Appendix A

Total Maximum Daily Loads of Nitrogen and Phosphorus for Five Tidal Tributaries in the Northern Coastal Bays System Worcester County, Maryland

FINAL

December 2001

MODELING FRAMEWORK

The computational framework chosen for the modeling of water quality in the Northern Coastal Bays was the Water Quality Analysis Simulation Program version 5.1 (WASP5.1). WASP5.1 is supported and distributed by U.S. EPA's Center for Exposure Assessment Modeling (CEAM) in Athens, GA (Ambrose *et al,* 1993). This program provides a generalized framework for modeling contaminant fate and transport in surface waters (Di Toro *et al*, 1983) and is based on the finite-segment approach. It is a very versatile program, capable of being applied in a time-variable or steady-state mode, spatial simulation in one, two or three dimensions, and using linear or non-linear estimations of water quality kinetics. To date, WASP5.1 has been employed in many modeling applications that have included river, lake, estuarine and ocean environments. The model has been used to investigate water quality concerns regarding dissolved oxygen, eutrophication, and toxic substances. WASP5.1 has been used in a wide range of applications by regulatory agencies, consulting firms, academic researches, and others. EUTRO5.1 is the component of WASP5.1 that is applicable for modeling eutrophication, incorporating eight water quality constituents in the water column (Figure A1) and sediment bed.

The Northern Coastal Bays eutrophication model (NCBEM) is based on a EUTRO5.1 model developed previously by Dr. Winston Lung of the University of Virginia (Lung, 1994). At the time of model development, Dr. Lung also developed a hydrodynamic model. The results of the hydrodynamic model are incorporated into the eutrophication framework and are considered in this application of the EUTRO5.1 model. This model was re-calibrated with recent data from the Maryland Department of the Environment (MDE), the Maryland Department of Natural Resources (DNR), and the Maryland Coastal Bays Program (MCBP). The EUTRO5.1 model was implemented in a steady-state mode. This mode of using WASP5.1 simulates constant flow and average waterbody volume over the tidal cycle. The tidal mixing is accounted for using dispersion coefficients and an additional set of model flows resulting from the hydrodynamic model. These two model components quantify the exchange of water volume and water quality constituents between EUTRO5.1 model segments. The model simulates an equilibrium state of the waterbody, which was applied to low flow, and average annual flow conditions. These cases are described in more detail below.

WATER QUALITY MONITORING

All readily available information was considered in this TMDL analysis. Several sources of recent water quality data were particularly useful in supporting the model calibration: MDE (1998), DNR (1998-1999), and MCBP (1997-2000). MDE's Field Operations Program staff collected physical and chemical samples in spring and summer of 1998. The physical parameters, dissolved oxygen, salinity, conductivity, and water temperature were measured *in situ* at each water quality monitoring station. Grab samples were also collected for laboratory analysis. The samples were collected at a depth of ½ m from the surface. Samples were placed in plastic bottles and preserved on ice until they were delivered to the University of Maryland Laboratory in Solomons, MD, or the Department of Health & Mental Hygiene in Baltimore, MD for analysis. The field and laboratory protocols used to collect and process the samples are summarized in Table A1 (MDE, April 2001).

The DNR data was collected as part of their Pfisteria monitoring program. The laboratory protocols are similar to those used by MDE. The MCBP maintains a volunteer monitoring program. The sampling and laboratory protocols used by the MCBP are explained in "Coastal Bays Volunteer Monitoring Program, Water Quality Monitoring Manual Maryland Coastal Bays Program, 1997." Table A2 shows the sampling dates for the data sets from the three programs. Figure A2 shows the locations of the sampling stations. Figures A3 – A7 show the high flow and low flow data for chlorophyll *a*, dissolved oxygen, dissolved inorganic nitrogen, dissolved inorganic phosphorus, and BOD (low flow only, no BOD data was collected during high flow).

The eutrophication model is calibrated for both high flow and low flow periods. Temporal and spatial data availability as well as temperature and flow measurements were examined to determine the appropriate data to include as part of each calibration. Comprehensive data, that covered both tidal and non-tidal waters, was limited to 1998. Due to this limited data availability, the time period chosen for each of the calibrations focused on this time period. MDE and DNR both collected data in the tributaries that drain to the Coastal Bays. The MCBP collected near-shore samples for both of the bays and most of the major tributaries. The model used for the Northern Coastal Bays is a steady-state depth averaged two-dimensional model, with relatively large segments. Due to the large size of the model segments, the near-shore data collected by the MCBP is not expected to be comparable to the outputs from the model. Thus, the MCBP data was not used for the calibration comparison of the model, however it was used in the evaluation of the estimated nonpoint source loads entering the system. The high flow calibration of the model was performed with data from April of 1998 (MDE: 4/14, 4/21, 4/26; DNR 4/30; MCBP 4/8 – 4/29). The low flow calibration of the model was performed with data from July, August, and September 1998 (MDE: 8/11, 9/1; DNR 7/29, 8/25; MCBP 7/24 – 8/24).

INPUT REQUIREMENTS [1]

Model Segmentation and Geometry

The spatial domain of the NCBEM includes the Isle of Wight Bay, Assawoman Bay, St. Martin River, Bishopville Prong, and Shingle Landing Prong extending to Church Branch. Some of the major tributaries to the Isle of Wight Bay (Herring Creek, Turville Creek and Manklin Creek) and Assawoman Bay (Greys Creek) were also included in the modeling domain. However, the large size of the model segments representing these tidal tributaries limits the degree to which the model can be used to determine water quality for these tributaries. Where the model has been used for these tributaries (Herring Creek and Turville Creek), the results have been characterized as a "Phased TMDL."

The model, developed in 1994 by Dr. Lung of the University of Virginia, included 30 water quality segments. Seven segments were added by MDE in Shingle Landing Prong and Church Branch to address the effects of a point source in that area. Figure A8 shows the model segmentation (modeling domain) of the NCBEM. Figure A8 also shows the subwatershed segmentation for the Northern Coastal Bays watershed. Table A3 lists the segment volumes and

1 The WASP model requires all input data to be in metric units, and to be consistent with the model, all data in the Appendix will appear in metric units except the river length. Following are several conversion factors to aid in the comparison of numbers in the main document: mgd x (0.0438) = m^3/s | cfs x (0.0283) = m^3/s | lb / (2.2) = kg | mg/l x mgd x (8.34) / (2.2) = kg/d

depths of the 37 segments. Table A4 lists the characteristic lengths and interfacial areas between segment pairs.

Dispersion Coefficients

The dispersion coefficients were calibrated using the EUTRO5.1 model and in-stream salinity data from 1998. As mentioned in the *Modeling Framework* section of this Appendix, the 1994 modeling work included a hydrodynamic model. The results of this model are incorporated into the EUTRO5.1 model by including an additional flow block to reflect the tidally induced circulation flow patterns provided by the hydrodynamic model. The effects of this block are adjusted based on the total flows to the system. The WASP5.1 model was set up to simulate salinity. As a conservative substance, there are no changes in concentration due to chemical or biological reactions in the water. Thus, concentration is solely determined by mixing. The only sources in the system are at the tidal boundaries. For the model execution, salinity values at all boundaries except the tidal boundaries were set to zero. As discussed above, the NCBEM was calibrated for two sets of flow conditions, high flow and low flow.

Estimated point and nonpoint source flows for the appropriate flow conditions were included as part of the calibration of the dispersion coefficients. The method used to calibrate the dispersion coefficients is described in more detail below. Figure A9 shows the results of the calibration of the dispersion coefficients for high flow and low flow. The same sets of dispersion coefficients were used for both the high flow and low flow calibrations of the model. The final values of the dispersion coefficients are listed in Table A4.

Freshwater Flows

In 1998, the model calibration period, there were no active USGS gages in the Northern Coastal Bays watershed. It was necessary to estimate flows for the "high" flow sampling period (spring), and the "low" flow period (late summer-early fall). These were estimated using an area to flow ratio approach described below. It should be noted that the term "high flow" in this context corresponds to the relatively higher flows observed in spring, and <u>not</u> to rare flood conditions.

The drainage basin was subdivided into 47 subwatersheds (Figure A8). These subwatersheds correspond to the subwatersheds used in the UVA study (Lung, 1994). A ratio of flow to area was determined for each subwatershed to estimate the flow from each. The flow to area ratio was calculated based on flow data from the nearby USGS gaging station 01485000 on the Pocomoke River near Willards, Maryland.

The flow ratio, corresponding to "high" (spring-time) flows, was calculated by averaging daily mean stream flow data from April 9 to May 5, 1998, and dividing by the gaged watershed area. The low flow ratio was calculated by averaging daily mean discharge data from July 1 to September 30, 1998, and dividing by the gaged watershed area. An additional set of flows for average annual conditions was calculated for use in model scenarios. An average flow ratio was calculated using the same method as for high and low flow, using discharge data from December 1949 to September 1998. Table A5 presents the flows from each subwatershed for high, low, and average flow conditions. Again, the term "high flow" corresponds to the relatively higher flows that occurred in spring 1998, rather than to high flows from a long-term flow record. In fact, as seen in Table A5, the 1998 spring "high" flow is estimated to correspond closely to the long-term average flow.

Point Source Loadings

Sources Considered

Seven point sources were considered in the TMDL analysis; however, there are only two discharges of nutrients in the study area that are given waste load allocations (See summary table below). These are the Ocean Pines Service Area Wastewater Treatment Plant (MD0023477), and the Perdue Farms processing plant in Showell, MD (MD0000965). Only the Ocean Pines plant and the Perdue Farms processing plant are significant enough to include explicitly in the model (see further discussion below). The Perdue Farms hatchery is accounted for as part of the loads to the upstream model boundary in the Bishopville Prong.

Several other point source discharges were considered, but are not directly included in the modeling analyses. The MountAire processing plant (DE0050326), in Delaware on the Bishopville Prong of the St. Martin River, only discharges non-contact cooling water. The process wastewater goes to the Selbyville, DE WWTP, which discharges outside of the watershed.

The Ocean City WWTP, the Selbyville, DE WWTP and the South Coast Regional, DE WWTP discharge to the Atlantic Ocean. If these contribute loads to the system, they would be accounted for in observed nutrient concentrations at the model boundary of the Isle of Wight Bay with the Atlantic Ocean. No allocations are given to these sources as part of this analysis.

Summary of Point Sources Considered

Point Source Name	Modeling Disposition	Allocation Disposition
Ocean City, MD WWTP	Discharges outside of Study Area	No Allocation Given
Selbyville, DE WWTP	Discharges outside of Study Area	No Allocation Given
South Coast Regional, DE WWTP	Discharges outside of Study Area	No Allocation Given
MountAire, DE plant	No net load to consider[1]	No Allocation Given
Perdue Farms processing (Showell)	Included Explicitly	Allocation Given
Perdue Farms hatchery (Bishopville)	Included in Background	No Allocation Given
Ocean Pines, MD WWTP	Included Explicitly	Allocation Given

1. MountAire discharges noncontact cooling water.

Model Calibration Consideration of Point Sources

As noted above, only the Ocean Pines Service Area WWTP and the Perdue Farms poultry processing plant in Showell, MD are simulated as direct discharges to the Northern Coastal Bays Eutrophication Model (NCBEM). The Ocean Pines WWTP discharges directly into the St. Martin River (model segment 13). The Perdue Farms poultry processing plant in Showell discharges to Church Branch (model segment 36) via an unnamed tributary. Church Branch in turn drains to the Shingle Landing Prong, a tributary of the St. Martin River. In 1998, the calibration period, these point sources were jointly contributing about 36,566 lbs/yr of nitrogen and 2,313 lbs/yr of phosphorus to the St. Martin River System.

The point source flows and nutrient loadings from the Ocean Pines WWTP and the Perdue Farms processing plant in Showell used for the model calibration were calculated from 1998 discharge monitoring report (DMR) data stored in MDE's Point Source database (MDE, 2001). The DMR data was supplemented with nitrate and nitrite data provided by Woody Vickers, Perdue Farms Inc. Specifically, data from April of 1998 was used for the high flow calibration of the model. An average of discharge data from July, August, and September of 1998 was used for the low flow calibration of the model. These data are summarized in Table A6.

The Perdue/Showell plant underwent a treatment process upgrade at the end of 1997, just prior to the water quality data collection period in 1998. The upgraded plant discharges were assumed in the model calibration process. However, because the plant was upgraded just prior to the field data collection, the model calibration process was conducted under the assumption that water quality properties observed in 1998 were influenced by sediment properties (higher nutrient fluxes and greater sediment oxygen demand {SOD}) that still reflected past effluent discharge practices. The sediment properties were changed to reflect the effects of the Perdue plant upgrade in the TMDL modeling scenarios described below.

The Perdue chicken hatchery (Bishopville) was not included as an explicit discharge to the NCBEM. It is estimated to contribute less than one-half of one percent of the load at the upstream water quality model boundary on Bishopville Prong (model segment 22) during low flow. The relative contribution is even less significant for higher flow conditions. This estimate is a conservative because it does not account for transport losses between the point of discharge and the upstream boundary of the model. The load is considered indirectly as part of the nutrient load at the upstream boundary. A table summarizing this estimate is provided below.

Although the combined flows from the Perdue hatchery and MountAire plant are very small (0.014 mgd), they were added to the estimated watershed flows (1.2 mgd at low flow) from Bishopville Prong for completeness. The flow information for MountAire was provided by John DeFriece, Delaware Department of Natural Resources and Environmental Control, and the flow from the Perdue hatchery was obtained from DMR data (MDE, 2001). For calibration purposes, the parameter concentrations at the boundary of the model in Bishopville Prong were based on observed data for high flow and low flow conditions respectively. These include the loads from both of the upstream plants.

Upstream Loads to Bishopville Prong Model Segment 22 During Low Flow Conditions Showing Very Small Relative Contribution of Purdue Hatchery

Load Source	Flow mgd[1]	TN kg/day	TP kg/day	Percentage of flow	Percentage of TN load	Percentage of TP load
Total Upstream [2]	1.2088	11.04	1.31	100	100	100
Purdue Hatchery	0.0040	0.044	0.005	0.3	0.4	0.4

Notes:
1. mgd = cfs/1.547

2. Total Upstream load is estimated based on flow and concentration values observed in 1998. See Table A8 for loads to model segment 22, where TN & TP are sums of nutrient species.
3. See Table A6 for 1998 estimates of point source discharges.

Model Scenario Consideration of Point Sources

For both the low flow and average flow conditions, the TMDL analysis considers two primary scenarios: Baseline scenarios, and TMDL scenarios. Briefly, the baseline scenarios for low and average flow conditions simulate a type of no-action situation. Point source flows and loads are increased to planned values with current or anticipated point source treatment technologies. Relatively current land use and nonpoint source loads are simulated, and associated bottom sediment properties are assumed (e.g., sediment nutrient flux). The TMDL scenarios simulate low flow and average flow conditions that correspond to the maximum allowable loads.

As noted above, only two point sources were significant enough to warrant explicit simulation in the NCBEM. These were the Ocean Pines WWTP, a municipal effluent source, and the Perdue Farms processing plant in Showell, MD, an industrial effluent source.

Municipal Discharges:

For municipal WWTPs, the baseline scenarios typically assume approved maximum sewer plan flows, and loads that are consistent with planned treatment, and the season simulated by the particular scenario. For the Ocean Pines WWTP discharge, flow of 3.0 mgd was used for the two baseline scenarios (low and average flows), as well as the two TMDL scenarios. Table A17 shows the values of other parameters used in the low flow and average flow baseline scenarios for the Ocean Pines WWTP. As discussed below, these same loading values were used in the TMDL scenarios.

The values in Table A17 correspond to a total nitrogen concentration of 3.0 mg/l during low flow conditions, and an average annual total nitrogen concentration of 8.0 mg/l for the Ocean Pines WWTP. A total phosphorus concentration of 2.0 mg/l is used in both the low flow and average flow baseline scenarios. For a relative comparison, the current low flow ("seasonal") point source goal in Maryland's Tributary Strategy for Nutrient Reduction under the Chesapeake Bay Agreement is a total nitrogen concentration of 8 mg/l, compared to 3.0 mg/l for Ocean Pines WWTP as noted above.

Because the baseline loads for Ocean Pines WWTP are very low, these same loads were used in the TMDL scenarios for low flow and average annual flow. These are summarized in a technical memorandum, which accompanies this TMDL, entitled *Significant Nutrient Point Sources and Nonpoint Sources in the Northern Coastal Bays System.*

Industrial Discharges:

The maximum flow volumes for discharges of industrial effluents directly to waters of the State are not established in local water and sewer plans. Rather, they are established on the basis of need and other considerations. The flow assumed for both the baseline and TMDL scenarios in the analysis is 1.2 mgd. Table A17 shows the values of other parameters used in the low flow and average annual flow baseline scenarios for the Perdue Farms processing plant in Showell, MD.

The values in Table A17 correspond to a total nitrogen concentration of 5.0 mg/l during low flow conditions, and an average annual total nitrogen concentration of 8.0 mg/l for the Perdue Farms plant in Showell. A total phosphorus concentration of 0.5 mg/l is used in both the low flow and average flow baseline scenarios. For a relative comparison, the current low flow ("seasonal") goal in the Chesapeake Bay Agreement is a total nitrogen concentration of 8 mg/l, compared to 5.0 mg/l for the Perdue, Showell plant as noted above. Further, the total phosphorus concentration of 0.5 mg/l compares with the 2.0 mg/l concentration associated with the Ocean Pines WWTP. The 0.5 mg/l concentration is dictated by the significantly less assimilative capacity of the stream below the Perdue plant.

The same point source loads used in the baseline scenarios for the Perdue/Showell plant were used in the TMDL scenarios. The logic for this rests on the fact that the Perdue/Showell plant underwent a treatment process upgrade at the end of 1997, just prior to the water quality data collection period in 1998. Because the plant was upgraded just prior to the field data collection, it was assumed that water quality properties observed in 1998 were influenced by sediment properties (nutrient fluxes and sediment oxygen demand {SOD}) that still reflected past effluent discharge practices. Thus, a key difference between the baseline scenarios and TMDL scenarios, were reductions in sediment nutrient fluxes, and SOD that reflect reduced loads from both the recent plant upgrade, and reductions proposed for nonpoint sources. The point source discharges simulated in the TMDL scenarios are summarized in a technical memorandum, which accompanies this TMDL, entitled *Significant Nutrient Point Sources and Nonpoint Sources in the Northern Coastal Bays System.*

Nonpoint Source Loadings

Nonpoint source loads were estimated for observed 1998 "high flow" (spring flows), observed 1998 "low flow" (summer/early-fall), and average annual loading conditions. The surface water nonpoint source loads for high flow and low flow conditions were estimated as the product of observed water quality concentrations and the nonpoint source flows estimated as described above. The observed sub-set of sampling dates used for each calibration is described in more detail in the *WATER QUALITY MONITORING* section of this Appendix. The sampling stations used to estimate each nonpoint source boundary concentration can be seen in Table A7.

The observed concentrations account for surface nonpoint source loads from all land uses, loads from septic tanks, atmospheric deposition to the land's surface, and base-flow groundwater loads. An additional nonpoint source load due to direct atmospheric deposition to the water surface was added to both the high flow and low flow nonpoint source loads used in the calibrations of the model. Direct groundwater discharge was included in the high flow calibration of the model. It was not included in the low flow calibration of the model because its effects were estimated to be negligible during low flow conditions. The nonpoint source loads used in the high flow and low flow calibrations of the model for nitrogen and phosphorus can be seen in Table A8 and Table A9 respectively.

The Average Annual NPS load estimate was used in the average annual baseline scenario and serves as a starting point in determining an estimate of the reduction needed to meet the average annual TMDL goal. Many methods were investigated to estimate average annual nonpoint source loads. MDE solicited information on previous studies of loads, loading rates, and loading models developed in the Coastal Bays, or similar coastal areas, from the following sources: Maryland Department of Natural Resources (DNR), the Chesapeake Bay Program (CBP), U.S. EPA, University of Maryland (UMCES), U. S. Geological Survey, U.S. Department of Interior, Delaware Department of Natural Resources and Environmental Control (DNREC), the University of Delaware, the consulting firm Aquaterra, and participants of MDE's Northern Coastal Bays TMDL technical workgroup.

The results of the above investigations produced the following sources for further examination: reported loading rates from the UMCES study "Maryland's Coastal Bays: An Assessment of Aquatic Ecosystems, Pollutant Loadings, and Management Options;" reported loads from the DNR/USGS study; "Upper Pocomoke, Calibration of the Agricultural BMP Evaluation 1994-1998;" CBP loading rates from watershed model segment 430 (Pocomoke Basin); loading information produced through the HSPF model MDE is developing in the Pocomoke Basin; data from the newly installed USGS gage on Birch Branch; methodologies presented in the U.S. Army Corps of Engineers/ Waterways Experimental Station report "Hydrodynamics and Eutrophication Model Study of Indian River and Rehoboth Bay, Delaware;" and methodologies used in the DNREC report "Total Maximum Daily Load Analysis, for Indian River, Indian River Bay, and Rehoboth Bay Delaware."

From these numerous investigations, four candidates presented themselves as the best options for further investigation as possible estimations of average annual NPS loads. These were the UMCES study, the CBP loading rates, the DNR/USGS study, and load estimates based on field data observed by MDE and DNR in 1998 and 1999. The NPS estimate based on field data was ruled out, for reasons described below, leaving the other three candidates for consideration.

Land use loading rates were derived from each of the three candidates noted above and applied to the land uses in the Coastal Bays using a area unit loading rate approach. The land use in the Northern Coastal Bays was calculated based on 1997 Maryland Department of Planning data, and included an adjustment to cropland acres using 1997 Farm Service Agency (FSA) data. The average annual nonpoint source load was calculated for each of the different loading rate options by summing all of the individual land use areas and multiplying by the corresponding land use loading coefficients.

The annual NPS load was also estimated by multiplying the MDE and DNR in-stream nutrient concentration data by the corresponding estimated mean daily flow and then taking an average of the resulting loads. It must be noted that no concentration measurements were taken during November, December, January, February, or March, the higher flow months that bring in a high percentage of the load, and all samples were taken in 1998 or 1999. Consequently, these values were used for comparison purposes only.

Two analyses were employed to support the choice of the most appropriate set of land use loading rates for use in estimating the average annual NPS load entering the Northern Coastal Bays. The first was a comparison of the annual load estimated using the in-stream data with each load calculated using the three sets of loading rates. Table A10 and Table A11 show the results of these comparisons for total nitrogen and total phosphorus respectively. As can be seen in the tables the loading rates from the DNR/USGS study produced the highest load, approximately 6.3 and 27.7 times higher than the loads estimated with in-stream data for total nitrogen and total phosphorus respectively. The loading rates from the CBP model produced the lowest load out of the three loading rate options. However, the total nitrogen load was still 4.1 times higher and the phosphorus load was 7.7 times higher than the loads estimated with in-stream data. The loading rates from the UMCES study were 2.6 and 8.7 times higher than the loads estimated with in-stream data for total nitrogen and total phosphorus respectively. These results are reasonable given that the load estimates based on in-stream data did not include observations from November through March when flows are generally higher and might contribute more load.

The second analysis used to evaluate the loading rate options was to use the three different NPS loads estimates in the model and compare the results to the range of observed data. Figure A10 shows the results of this comparison. As can be seen from the figure, the loading rates from the UMCES study produced results that fell most closely in the range of the observed values. Both of these comparisons were presented to MDE's Northern Coastal Bays TMDL technical workgroup. It was agreed that MDE should use the loading rates from the UMCES study for the development of the average annual TMDL.

One particular issue was to estimate the average annual urban loading rate to be used for Ocean City (Fenwick Island). This area is unique in this watershed in that it is almost 100 % impervious urban land. Due to this difference, MDE considered additional options for estimating the average annual urban load for Ocean City. MDE investigated urban loading rates in highly impervious areas of Baltimore City and Baltimore County based on both observed data and simulated information. Lacking any better information, it was assumed that Ocean City will have a similar nutrient urban loading rate to these areas due to the similarity in impervious area (i.e. primarily impervious urban). The Baltimore City values (Hamilton Avenue and Radecke Avenue) were obtained from the 1999 City of Baltimore NPDES Storm Water Annual Report (March 2000), and reflect actual measured data. The Back River values represent the resulting loading rates from a Stormwater Management Model (SWMM) originally developed for Baltimore County (October, 1996), and were refined by staff at MDE as part of an unrelated project. Table A12 shows a comparison of the urban loading rates considered for Ocean City. Table A12 breaks the Baltimore City and Baltimore County loading rates into base flow and storm flow. Due to the small watershed size of Ocean City, it was assumed that there would be very little load due to base flow. Thus, the estimated total nitrogen loading rate for Ocean City, of 7.6 lb/ac/yr, reflects a value between the storm flow load (5-6 lb/ac/yr) and total annual load (8.5 – 10 lb/ac/yr). An analogous approach was used for total phosphorus. Table A12 also shows the estimated urban loading rates assumed for Ocean City (NCBEM), and other urban loading rates used for comparison.

The average annual loading rates used in the final analysis reflect loads coming from urban development, agriculture, and forestland. An additional nonpoint source load due to direct atmospheric deposition to the water surface was included, as well as a load due to direct groundwater discharge. The atmospheric deposition load was calculated by multiplying the surface area of each water quality segment by a loading coefficient. The atmospheric loading coefficient was based on the results of the Chesapeake Bay Model (U.S. EPA, 1996) segment 430 (Pocomoke River), which was a continuous simulation model.

The direct groundwater loads included in both the high flow and average annual loads were estimated based on methods described in the USGS report "Ground-Water Discharge and Nitrate Loadings to the Coastal Bays of Maryland" (Dillow and Greene, 1999). The direct discharge to the Northern Coastal Bays was separated out from the total by Jonathan Dillow, USGS. The total annual direct discharge load was then distributed to the water quality segments based on the segment perimeters. The direct groundwater load is assumed to account for loads from septic tanks among other sources. The average annual total nitrogen and total phosphorus loads are presented in Table A13.

For all nonpoint source inputs, the concentrations of the nutrients nitrogen and phosphorus are modeled in their speciated forms. The WASP5.1 model simulates nitrogen as ammonia (NH_3), nitrate and nitrite (NO23), and organic nitrogen (ON); and phosphorus as ortho-phosphate (PO_4) and organic phosphorus (OP). Ammonia, nitrate and nitrite, and ortho-phosphate represent the dissolved forms of nitrogen and phosphorus. The dissolved forms of nutrients are more readily available for biological processes such as algae growth, which can affect chlorophyll *a* levels and dissolved oxygen concentrations. The ratios of total nutrients to dissolved nutrients used in the model scenarios represent values that have been measured in the field.

Environmental Conditions

Eight environmental parameters were used for developing the model of the Northern Coastal Bays. They are solar radiation, photoperiod, temperature (T), extinction coefficient (K_e), salinity, sediment oxygen demand (SOD), sediment ammonium flux (FNH_4), and sediment phosphate flux (FPO_4) (Table A14).

The light extinction coefficient, K_e in the water column was derived from Secchi depth measurements using the following equation:

$$K_e = \frac{1.95}{D_s}$$

where:

K_e = light extinction coefficient (m^{-1})
D_s = Secchi depth (m)

Varying SOD, FNH_4, and FPO_4 values were used for different sections of the NCBEM segmentation, where "F" indicates these are due to sediment fluxes. Initial values were taken from the 1994 model and then adjusted through the calibration process. Several studies, data sets, and literature sources were reviewed to determine appropriate ranges of values for use with the model: Cerco et al., 1994, Seitzinger and DeKorsey, 1994, Sampou, 1994, Mirsajadi, 2000, UMCES, 1999, Institute of Natural Resources, 1986, and Thomann, 1987. All values used in the model are within reasonable ranges predicted to occur in the Northern Coastal Bays. In general, lower nutrient flux and SOD values occurred in the open bays, while higher values were assumed in the upper reaches of the tributaries. During the high flow period, cooler temperatures and reduced biological activity reduce the expected nitrogen and phosphorus fluxes from the sediment. Thus, during the high flow period, the simulated ammonium flux was reduced by 75% and the ortho-phosphate flux by 90%.

Nonliving organic nutrient components and phytoplankton settle from the water column into the sediment at various rates throughout the system (Table A15). In general, it is reasonable to assume that 30-40% of the nonliving organics are in the particulate form, and that 10% of the inorganic phosphorus is in the particulate form. Such assignments were borne out through model sensitivity analyses.

Kinetic Coefficients

The water column kinetic coefficients are universal constants used in the NCBEM model. They are formulated to characterize the kinetic interactions among the water quality constituents. The initial values were taken from the eutrophication model developed in 1994. Kinetic coefficients from past modeling studies of Potomac River (Clark and Roesh, 1978; Thomann and Fitzpatrick, 1982; Cerco, 1985), and of Mattawoman Creek (Haire and Panday, 1985; Panday and Haire, 1986; Domotor *et al*., 1987), and the Patuxent River (Lung, 1993) were also reviewed. The final kinetic coefficients are listed in Table A16.

Initial Conditions

The initial conditions used in the model were chosen to reflect the observed values as closely as possible. However, it was found that the final results are independent of initial conditions.

CALIBRATION

The NCBEM model for low flow was calibrated with July, August and September 1998 data. The NCBEM was also calibrated for a high flow period with April 1998 data. Tables A5, A6, and A8 show the point source and nonpoint source flows and loads associated with the input files used for the calibrations of the model (See *Point Source Loadings and Nonpoint Source Loadings* above). Figures A11-A13 show the results of the low flow calibration of the model for the major and minor tributaries of the coastal bays. Figure A12 shows the calibration of the model for major tributaries and the open bays. The model has captured almost all of the state variables except for ammonia in the Bishopville Prong where it is shown to have been a little bit higher side. Figure A12 and Figure A13 show the calibration results of the model for the minor tributaries: Turville Creek and Herring Creek. Though there are not enough water quality segments to address the calibration in a finer scale, the model has seen to capture the average trend of all the state variables pretty well except for nitrite plus nitrate concentrations, where it is shown to capture the lower concentrations. Figures A14- A16 show the model results for the high flow calibration of the major and minor tributaries. All the major variables are captured pretty well.

SYSTEM RESPONSE

The EUTRO5.1 model of the Northern Coastal Bays was applied to several different nonpoint source loading conditions under various stream flow conditions to project the impacts of nutrients on algal production (chlorophyll *a)*, and dissolved oxygen. By simulating various stream flows, the analysis accounts for seasonality.

Model Run Descriptions

The first scenario represents the baseline conditions of the stream during low flow. The base-line scenario simulates a type of no-action situation, thus providing a stable point of comparison with the TMDL scenario. Point source flows and loads are increased to planned values under current or anticipated point source treatment technologies. Relatively current land use and nonpoint source loads are simulated, and associated bottom sediment properties are simulated. In this case, the nonpoint source flows and loads were the same as those used in the low flow calibrations of the model (Tables A5 and A8). The flow was estimated using a regression analysis as described above. The total nonpoint source loads were computed as the product of observed 1998 base-flow concentrations and the estimated critical low flow with an additional load included to account for direct atmospheric deposition to the water's surface. Because the loads are based on observed concentrations, they account for all natural and human-induced sources.

The point source loads were increased to reflect maximum possible loading conditions under existing or draft permits. The maximum load at the Perdue processing plant in Showell was calculated based on the plant's draft NPDES permit published on December 28, 2000. It should be noted, however, that the Perdue/Showell plant underwent an upgrade in 1997. (See discussion, under "The TMDL Scenarios" below). The maximum load at the Ocean Pines WWTP was calculated by multiplying the plant's maximum approved water and sewer plan flow by their current NPDES permitted concentrations. The point source loads from the Perdue Hatchery in Bishopville and Mount Aire were calculated as described above; however, the flows were increased to reflect the maximum permitted flows. The point source loads for Scenario 1 are presented in Table A17. All the environmental parameters and kinetic coefficients established by the low flow calibration of the model remained the same for Scenario 1.

The second scenario represents the baseline conditions of the stream during average flow. The base-line scenario simulates a type of no-action situation, thus providing a stable point of comparison with the TMDL scenario. Point source flows and loads are increased to planned values under current or anticipated point source treatment technologies. Relatively current land use and nonpoint source loads are simulated, and associated bottom sediment properties are assumed. The average annual flows and nonpoint source loads were calculated as described above. The nonpoint source loads included direct groundwater discharge and direct atmospheric deposition to the water's surface. The nonpoint source loads are presented in Table A13.

The point source loads for phosphorus are the same as Scenario1. The total nitrogen concentrations used to calculate the load represent an annual average, which is higher than the concentrations in the summer. The point source loads used in Scenario 2 can be seen in Table A17. The method used to estimate average annual nitrogen and phosphorus loads did not include estimations of dissolved oxygen, chlorophyll *a*, and BOD boundary loads. These boundary loads were calculated by taking an average of all the 1998 data, using the stations in Table A7 to estimate each boundary value. The kinetic coefficients remained the same as for Scenario 1. The environmental parameters: temperature, salinity, extinction coefficients, fraction of daylight, and solar radiation represent an average of data or information from June through October (Table A18). The higher solar radiation and temperature during this period represent conservative assumptions as a margin of safety.

<u>The TMDL scenarios</u> (Scenario 3 and Scenario 4) were the result of a number of iterative model scenarios involving nutrient reductions that were explored to determine the maximum allowable loads. The third and fourth scenarios yield the water quality response for the maximum allowable loads for low flow and average annual cases respectively.

Model sensitivity analyses were performed to ascertain whether the model predicted nitrogen or phosphorus to limit algal growth during the different flow regimes. Under low flow conditions, the model was not sensitive to reductions in phosphorus, indicating a nitrogen-limited system. Under average flow conditions, the model was not sensitive to reductions in nitrogen, indicating a phosphorus-limited system. These model findings are consistent with nutrient limitation analyses based on the water quality data.

During the calibration period, 1998, the Perdue processing plant in Showell implemented major improvements to their plant. The ammonia load decreased by 67% between 1997 and 1998. The average annual total nitrogen load reduction from Perdue between 1997 and the annual baseline scenario (Scenario 2) was estimated to be 59%. These reductions are expected to have a major impact on the water quality in Church Branch and Shingle Landing Prong. The bottom sediment fluxes that were established during the low flow calibration of the model reflect the carry-over effects of loads to the system before the Perdue processing plant upgrade. Scenario 3 and Scenario 4 reflect reduced ammonium fluxes from bottom sediments. Table A19 shows the percent reductions assumed for segments 14 – 18 (St. Martin River) and 19, 31-37 (Shingle Landing Prong) due to changes in the load from the Perdue processing plant in Showell.

Sediment fluxes were also decreased proportionally in relation to nonpoint source load reductions assumed as part of each scenario. Along with reductions in nutrient fluxes from the sediments, when the nutrient loads to the system are reduced, the sediment oxygen demand was also reduced (US EPA, 1997). It was assumed that the SOD would be reduced in the same proportion as the reduction in nitrogen fluxes.

Simulated reductions in nutrients affect the initial concentrations of chlorophyll *a* in the fresh water flows at the model boundaries. To estimate the chlorophyll *a* reductions, the amount of nitrogen and phosphorus available for algae growth was calculated based on reduced nutrient loads. The maximum possible amount of chlorophyll *a* that could be grown was calculated twice, once assuming nitrogen was the limiting nutrient, and again assuming phosphorus was the limiting nutrient. The lower of two values was compared to the baseline scenario boundary value for chlorophyll *a*, and the lower of these three values was then taken to be the boundary for average flow based on principles of nutrient limitations.

The NCBEM calculates the daily average dissolved oxygen concentrations in the stream. This is not necessarily protective of water quality when one considers the effects of diurnal dissolved oxygen variation due to photosynthesis and respiration of algae. The photosynthetic process centers about the chlorophyll *a* containing algae, which utilize radiant energy from the sun to convert water and carbon dioxide into glucose, and release oxygen. Because the photosynthetic process is dependent on solar radiant energy, the production of oxygen proceeds only during daylight hours. Concurrently with this production, however, the algae require oxygen for respiration, which can be considered to proceed continuously. Minimum values of dissolved oxygen usually occur in the early morning predawn hours when the algae have been without light for the longest period of time. Maximum values of dissolved oxygen usually occur in the early afternoon. The diurnal range (maximum minus minimum) may be large and if the daily mean level of dissolved oxygen is low, minimum values of dissolved oxygen during a day may approach zero and hence create a potential for fish kill. A 1998 study performed on the Pocomoke, captured 24-hour dissolved oxygen measurements from May through September (Boynton and Burger, 1999). This study found that the magnitude of diurnal change in the Pocomoke River was typical of other Chesapeake Bay tributaries, amounting on average to about 2.0 mg/l-day for chlorophyll *a* concentration ranging from 50-100 µg/l and 0.5 mg/l-day for chlorophyll *a* concentration averaging 25 µg/l. Using this as a guide line, the following scenarios include an additional 1.0 mg/l margin of safety to protect for the diurnal variation of dissolved oxygen in the areas of high algal concentration and a 0.3 mg/l margin of safety to protect for the diurnal variation of dissolved oxygen in the areas where the algal concentration averages around 25 µg/l. Thus, the goal for the final scenarios will be a dissolved oxygen concentration of 6 mg/l and 5.3 mg/l respectively.

<u>The third scenario</u> represents improved conditions associated with the maximum allowable loads to the stream during critical low flow (Low Flow TMDL Scenario). Under low flow conditions, the algal growth is nitrogen limited. The stream flows, and nonpoint source loads from which reductions were estimated, were the same as the baseline Scenario 1. All of the environmental parameters (except sediment nutrient fluxes and SOD) and kinetic coefficients used for the calibration of the model remained the same as the baseline Scenario 1.

The nonpoint source load of total nitrogen from runoff was reduced by 31% and the direct atmospheric deposition load of nitrogen to the water's surface was reduced by 20%. It is reasonable to estimate that the direct nitrogen atmospheric deposition loads can be reduced by 20% due to anticipated actions under the Clean Air Act. This is consistent with reductions in the "TMDL analysis for Indian River, Indian River Bay, and Rehoboth Bay, Delaware (December, 1998)." Ammonium sediment fluxes were reduced 20% throughout the Northern Coastal Bays system to account for the effects of the reductions of nonpoint source total nitrogen. Additional reductions in ammonium fluxes were made in the St. Martin system, ranging from 10% at the mouth (segment 14) to 59% in Shingle Landing Prong (Segments 19-35) to account for reductions made as a result of upgrades at the Perdue plant in Showell. The same percentage reductions were made in sediment oxygen demand (SOD) (20% throughout the St. Martin System and the Herring and Turville Creek, with additional reductions in the St. Martin System as explained earlier). The ortho-phosphate sediment fluxes were assumed to be the same as the low flow baseline scenario.

The point source loads reflect maximum design flows and current/draft NPDES permit concentrations. More information about point source loads can be found in the technical memorandum entitled "Significant Nutrient Point Sources and Nonpoint Sources in the Northern Coastal Bays System," and in the section entitled *INPUT REQUIREMENTS* above.

In addition to implicit margins of safety discussed below, an explicit margin of safety was included in this scenario. It was computed as 5% of the allowable nonpoint source and direct atmospheric deposition loads.

<u>The fourth scenario</u> represents improved conditions associated with the maximum allowable loads to the stream during average annual flow (Average Annual TMDL Scenario). Under

average annual flow conditions, the algal growth is phosphorus limited. The stream flows, and nonpoint source loads from which reductions were estimated, were the same as the baseline Scenario 2. All the environmental parameters (except nutrient fluxes and SOD) and kinetic coefficients used for the calibration of the model remained the same as Scenario 2.

The nonpoint source load of total phosphorus from runoff loads were reduced by 19% in the St. Martin System and 13% in the Herring and Turville Creeks. Although phosphorus is the limiting nutrient, the nonpoint source runoff nitrogen loads were reduced by 31% to support the 31% reduction necessary to meet water quality standards for the low flow scenario. This is justified because low flow nitrogen loads are due primarily to base-flow, which are generated by infiltration of nutrients throughout the year. In addition, the direct atmospheric deposition of nitrogen to the water's surface was reduced by 20% under the assumption that the load reductions are throughout the year. Ammonium fluxes were reduced by 20% throughout as in the Third Scenario. The same percentage reductions were made in sediment oxygen demand (SOD) (20% throughout the St. Martin System and the Herring and Turville Creek, with additional reductions in the St. Martin System as explained earlier). An ortho-phosphate sediment flux reduction of 15% was included to account for the total phosphorus nonpoint source load reductions.

The point source loads reflect maximum design flows and current/ draft NPDES concentrations on an average annual basis. More information about point source loads can be found in the technical memorandum entitled "*Significant Nutrient Point Sources and Nonpoint Sources in the Northern Coastal Bays System*," and in the section entitled *INPUT REQUIREMENTS* above.

In addition to implicit margins of safety discussed below, an explicit margin of safety was included in this scenario. It was computed as 5% of the allowable nonpoint source and direct atmospheric deposition loads.

Scenario Results

<u>Baseline Scenarios</u>:

1. *Low Flow (Scenario 1):* Simulates critical low stream flow conditions during summer season. Surface water quality parameters (e.g., nutrient concentrations) are based on 1998 observed data. An additional load due to direct atmospheric deposition is also included. Point source loads are based on current or draft NPDES permit concentration multiplied by maximum design flows.

2. *Average Annual Flow (Scenario 2):* Simulates average stream flow conditions, with average annual nonpoint source loads estimated on the basis of 1997 land use, and unit area nutrient loading rates (UMCES, 1993). Point source loads are based on current or draft NPDES permit concentration multiplied by maximum design flows.

The two baseline scenarios represent the conditions when water quality is impaired by high chlorophyll *a* levels, and low dissolved oxygen concentrations. The results for Scenario 1 and Scenario 2 can be seen in Figure A17 through Figure A20 respectively.

In Scenario 1, for low flow conditions, the peak chlorophyll *a* level is around the value of 85 µg/l in the Shingle Landing and Bishopville Prong, which is above the management goal of 50 µg/l. The dissolved oxygen level in the St. Martin River and its tributaries is below the analysis threshold of 6.0 mg/l. Recall that the threshold of 6.0 mg/l is used to account for diurnal variations in dissolved oxygen, where chlorophyll *a* concentrations range from 50-100 µg/l.

Scenario 2, for average flow conditions, shows high chlorophyll *a* values in the Shingle Landing Prong, typical values exceeding 87 µg/l. The dissolved oxygen is above the analysis threshold of 6.0 mg/l throughout the St. Martin System.

For Herring Creek and Turville Creek, the Scenario2 (Figure A19 and Figure A20) shows no problem with the excessive algal concentration, but the dissolved oxygen is predicted to be below the standard of 5.0 mg/l (well below the proposed goal of 5.3 mg/l). Recall that the dissolved oxygen threshold of 5.3 mg/l is used to account for diurnal variations in dissolved oxygen, where chlorophyll *a* concentrations averages around 25 µg/l.

<u>Future Condition TMDL Scenarios</u>:

3. *Low Flow (Scenario 3):* Simulates the future condition of maximum allowable loads for critical low stream flow conditions during summer season.

4. *Average Flow (Scenario 4):* Simulates the future condition of maximum allowable loads for average annual stream flow conditions.

The results of the scenarios indicate that the water quality targets for dissolved oxygen and chlorophyll *a* are satisfied at all locations within the Northern Coastal Bays system under consideration in the analysis. The results of Scenario 3 are presented in Figure A17. The results show the standards have been met throughout the bay system under consideration in the analysis. The results of Scenario 4 are presented in Figure A18 through Figure A14 respectively. Figure A18 presents the results for the major tributaries and the open bays, while Figure 19 and Figure 20 present the result for the two minor tributaries Herring Creek and the Turville Creek. With the desired load reduction as mentioned above the water quality standards are met through out the bay system under consideration in the TMDL establishment.

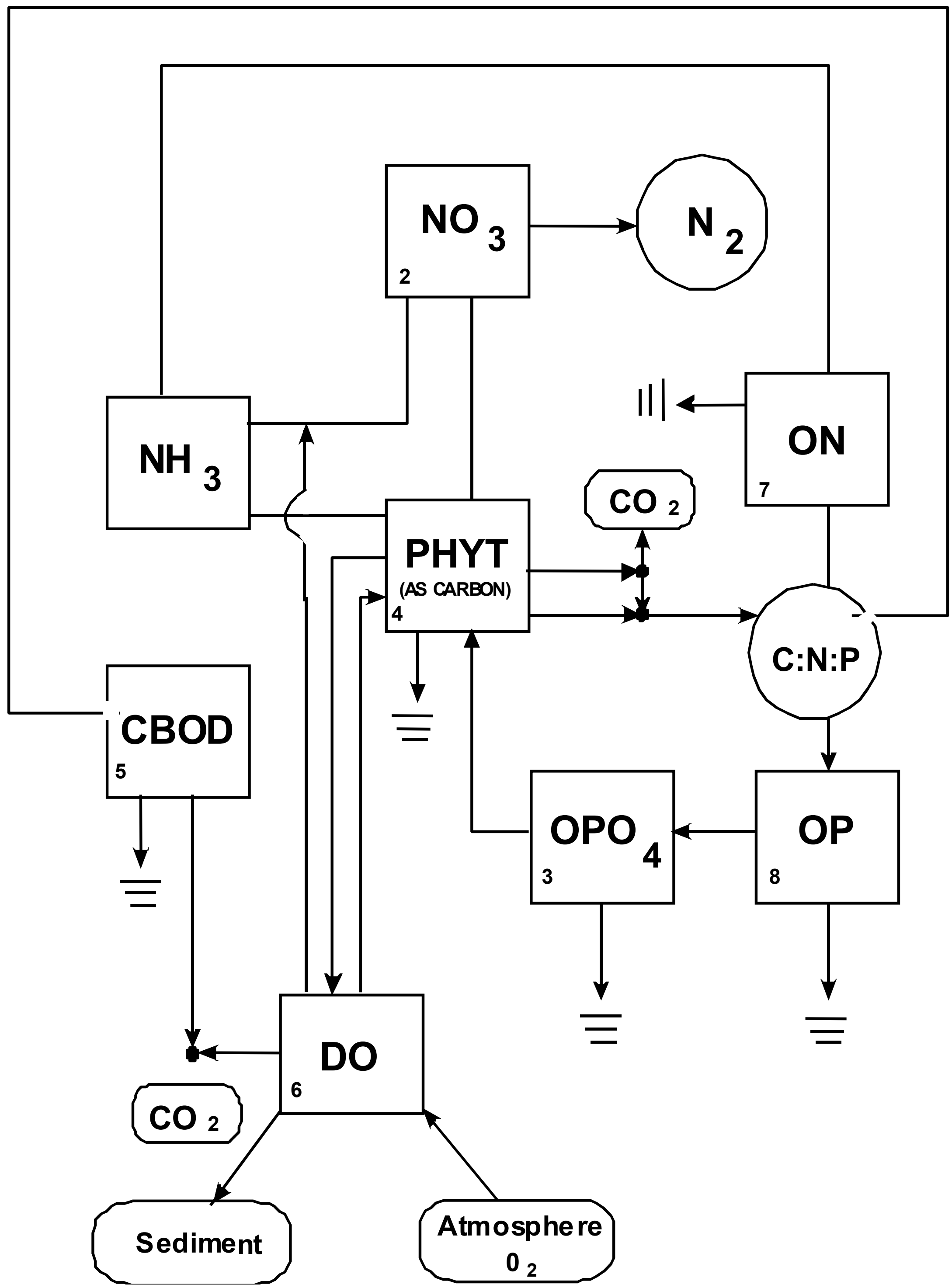


Figure A1: State Variables and Kinetic Interactions in EUTRO5

Table A1: Field and Laboratory Protocols

Parameter	Units	Detection Limits	Method Reference
IN SITU:			
Flow	cfs	0.01 cfs	Meter (Marsh-McBirney Model 2000 Flo-Mate)
Temperature	degrees Celsius	-5 deg. C to 50 deg. C	Linear thermistor network; Hydrolab Multiparameter Water Quality Monitoring Instruments Operating Manual (1995) Surveyor 3 or 4 (HMWQMIOM)
Dissolved Oxygen	mg/L	0 to 20 mg/l	Au/Ag polargraphic cell (Clark); HMWQMIOM
Conductivity	micro Siemens/cm (μS/cm)	0 to 100,000 μS/cm	Temperature-compensated, five electrode cell Surveyor 4; or six electrode Surveyor 3 (HMWQMIOM)
pH	pH units	0 to 14 units	Glass electrode and Ag/AgCl reference electrode pair; HMWQMIOM
Secchi Depth	meters	0.1 m	20.3 cm disk
GRAB SAMPLES:			
Ammonium	mg N / L	0.003	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Nitrate + Nitrite	mg N / L	0.0007	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Nitrite	mg N / L	0.0003	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Total Dissolved Nitrogen	mg N / L	0.03	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Particulate Nitrogen	mg N / L	0.0123	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Ortho-phosphate	mg P / L	0.0007	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Total Dissolved Phosphorus	mg P / L	0.0015	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Total Phosphorus	mg P / L		Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Particulate Phosphorus	mg P / L	0.0024	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Dissolved Organic Carbon	mg C / L	0.15	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Particulate Carbon	mg C / L	0.0759	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Silicate	mg Si / L	0.01	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Total Suspended Solids	mg / L	2.4	Chesapeake Biological Laboratory. Standard Operating Procedures. TR No. 158-97
Chlorophyll *a*	μg/L	1 mg/cu.M	Standard methods for the Examination of Water and Wastewater (15th ed.) #1002G. Chlorophyll. Pp 950-954
BOD_5	mg/l	0.01 mg/l	Oxidation ** EPA No. 405

Table A2: Sampling Dates for Water Quality Data

Sampling Dates	Source
April 14, 1998	MDE
April 21, 1998	MDE
April 28, 1998	MDE
August 11, 1998	MDE
September 1, 1998	MDE
September 29, 1998	MDE
April 30, 1998	DNR
June 29, 1998	DNR
July 29, 1998	DNR
August 25, 1998	DNR
September 29, 1998	DNR
October 20, 1998	DNR
April 21, 1999	DNR
May 19, 1999	DNR
August 1998 to February 2000 sampled approx. once monthly	MCBP- Volunteer

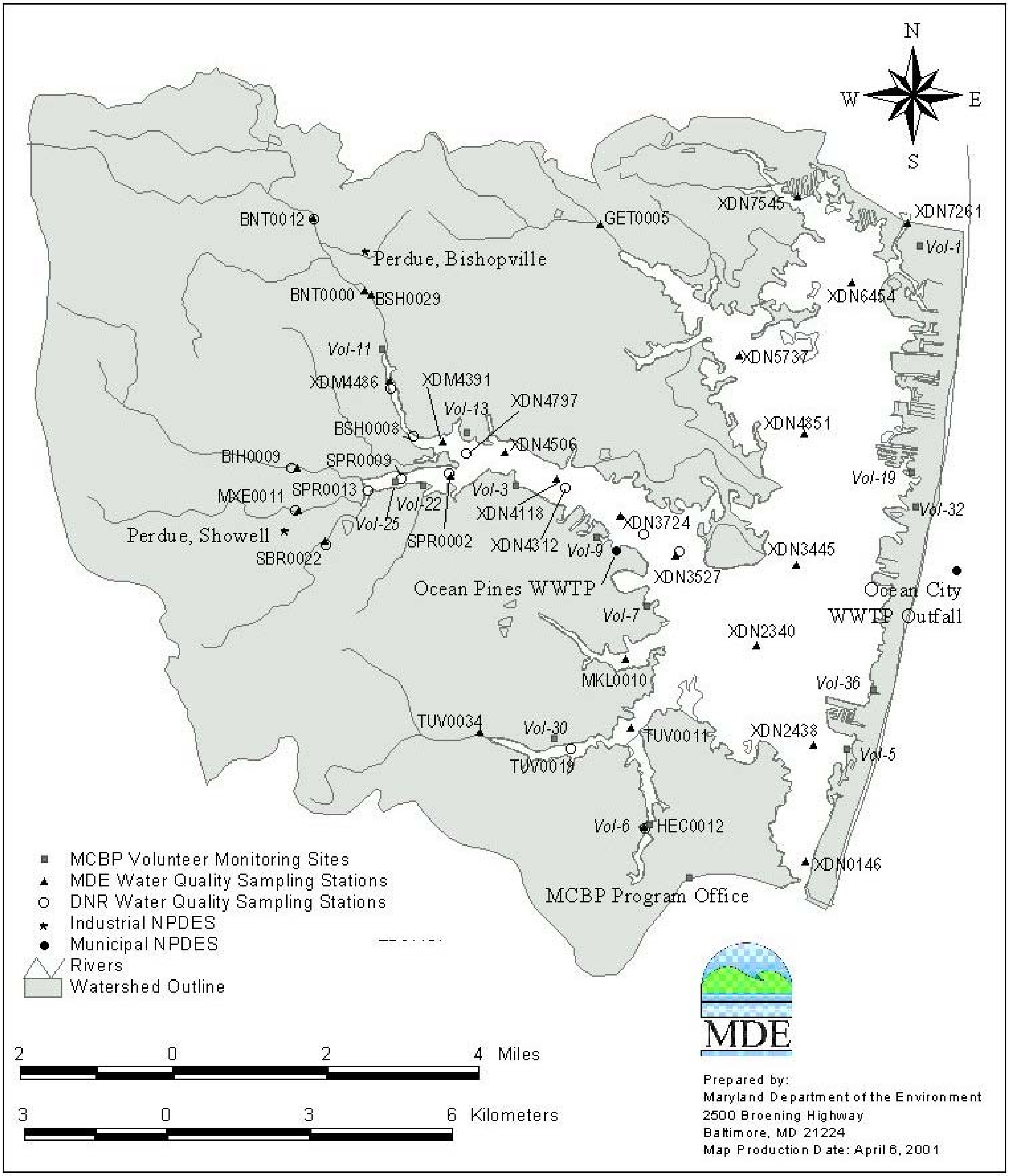


Figure A2: Water Quality Monitoring Stations in the Northern Coastal Bays

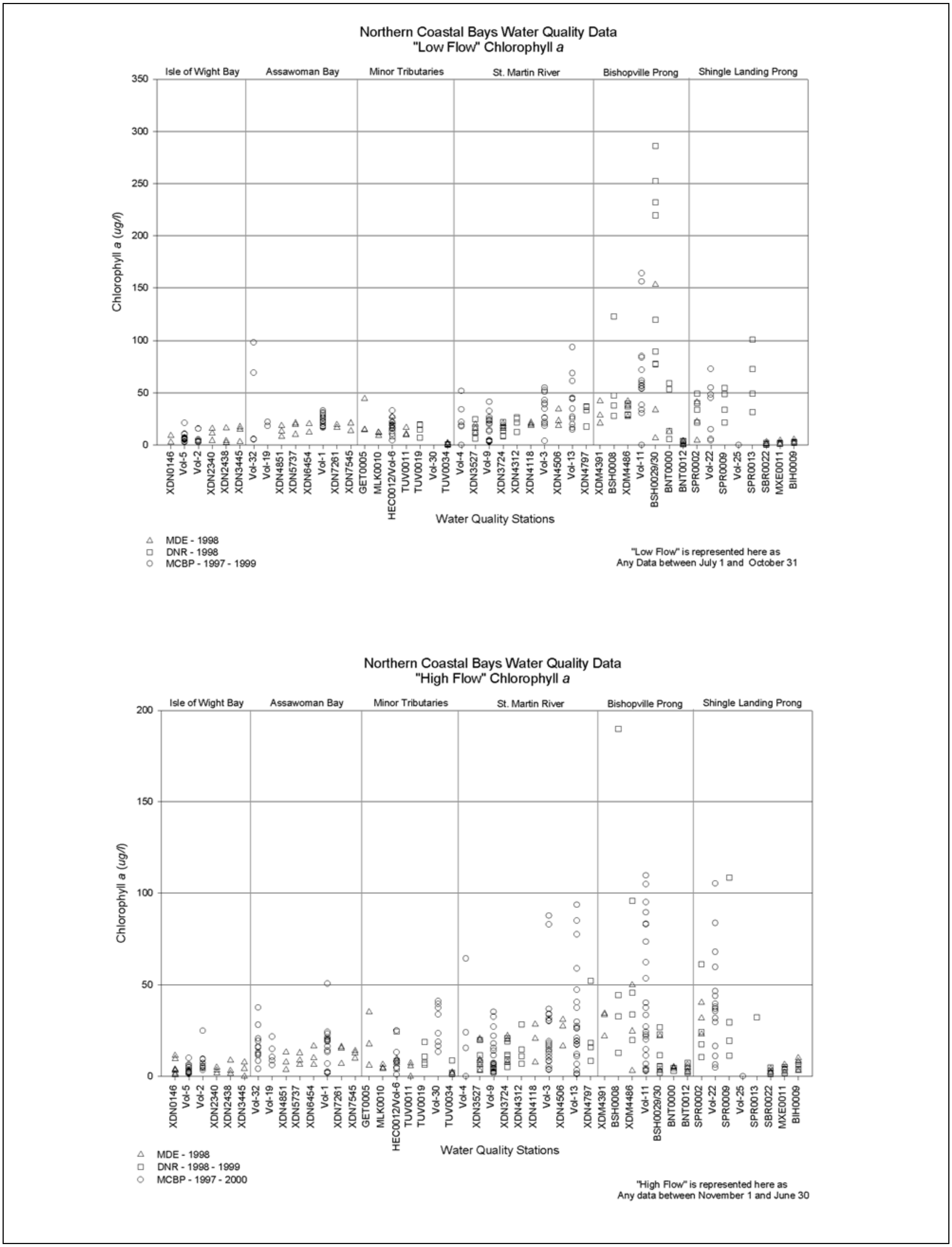


Figure A3: Profile of Chlorophyll *a* Data

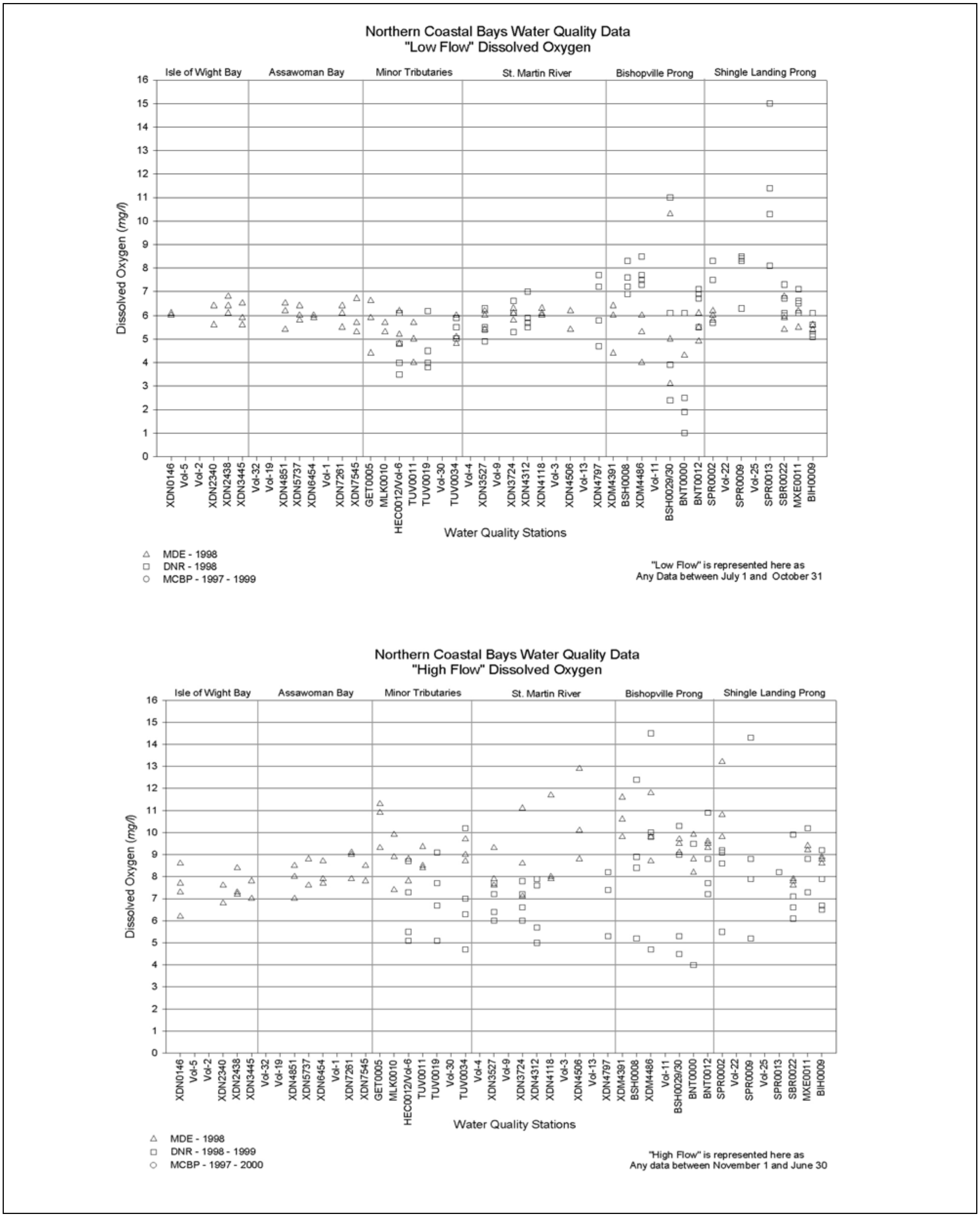


Figure A4: Profile of Dissolved Oxygen Data

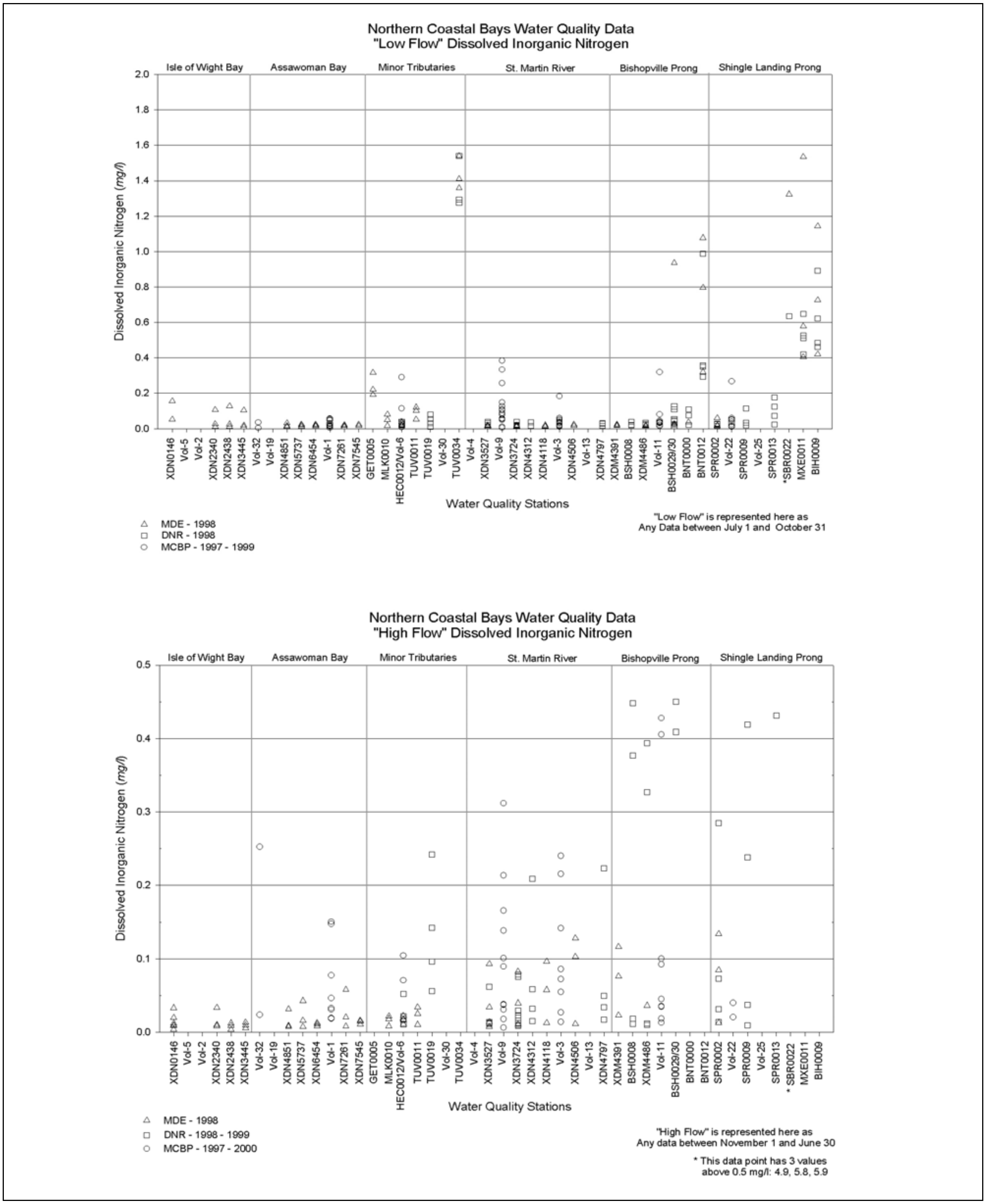
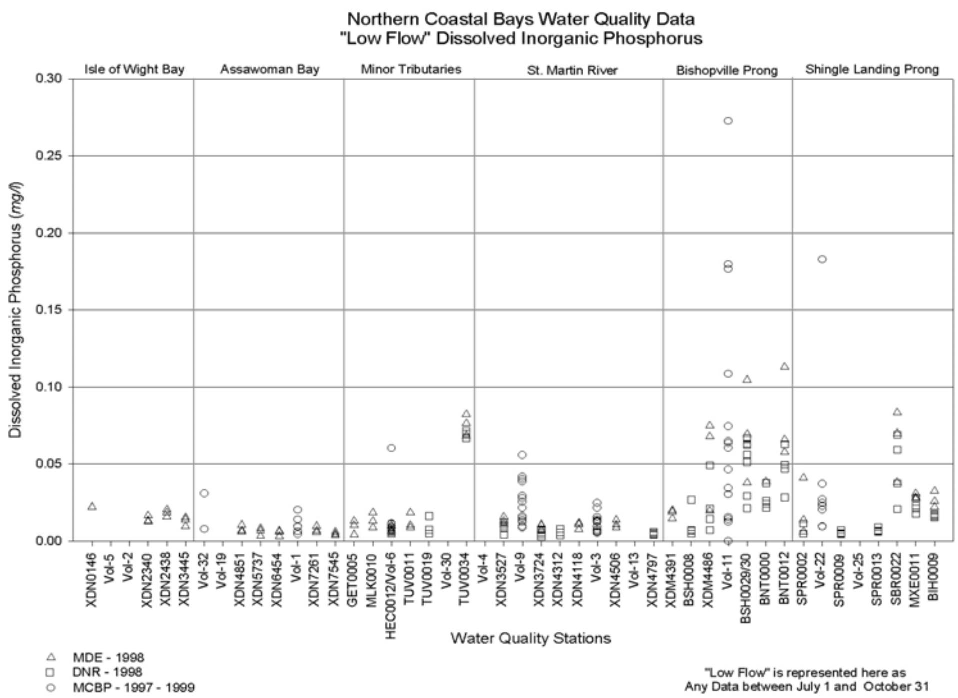


Figure A5: Profile of Dissolved Inorganic Nitrogen Data



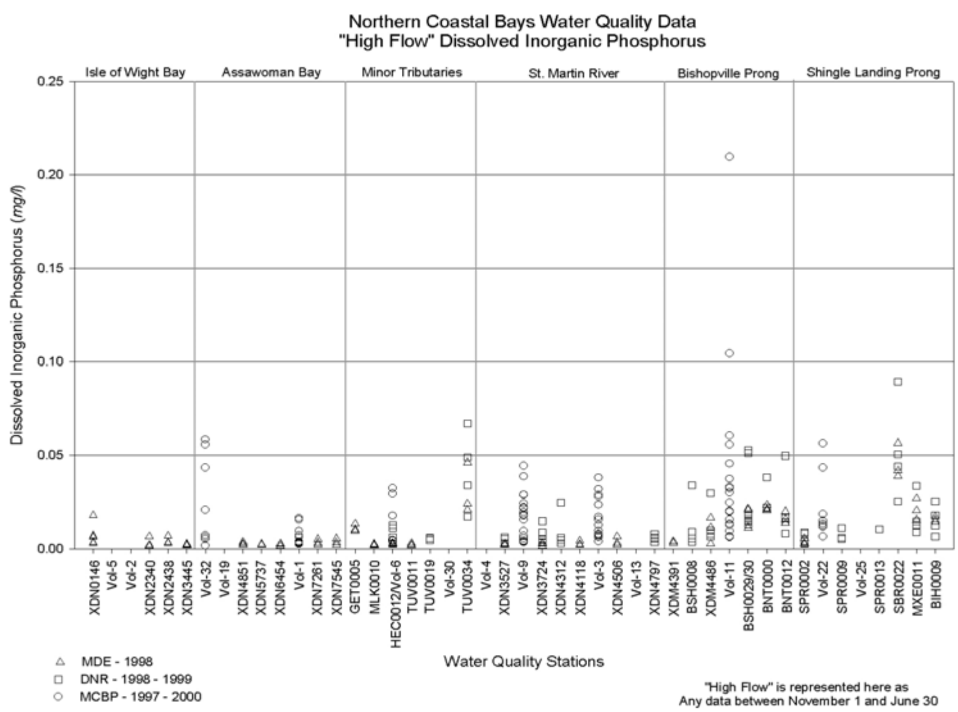


Figure A6: Profile of Dissolved Inorganic Phosphorus Data

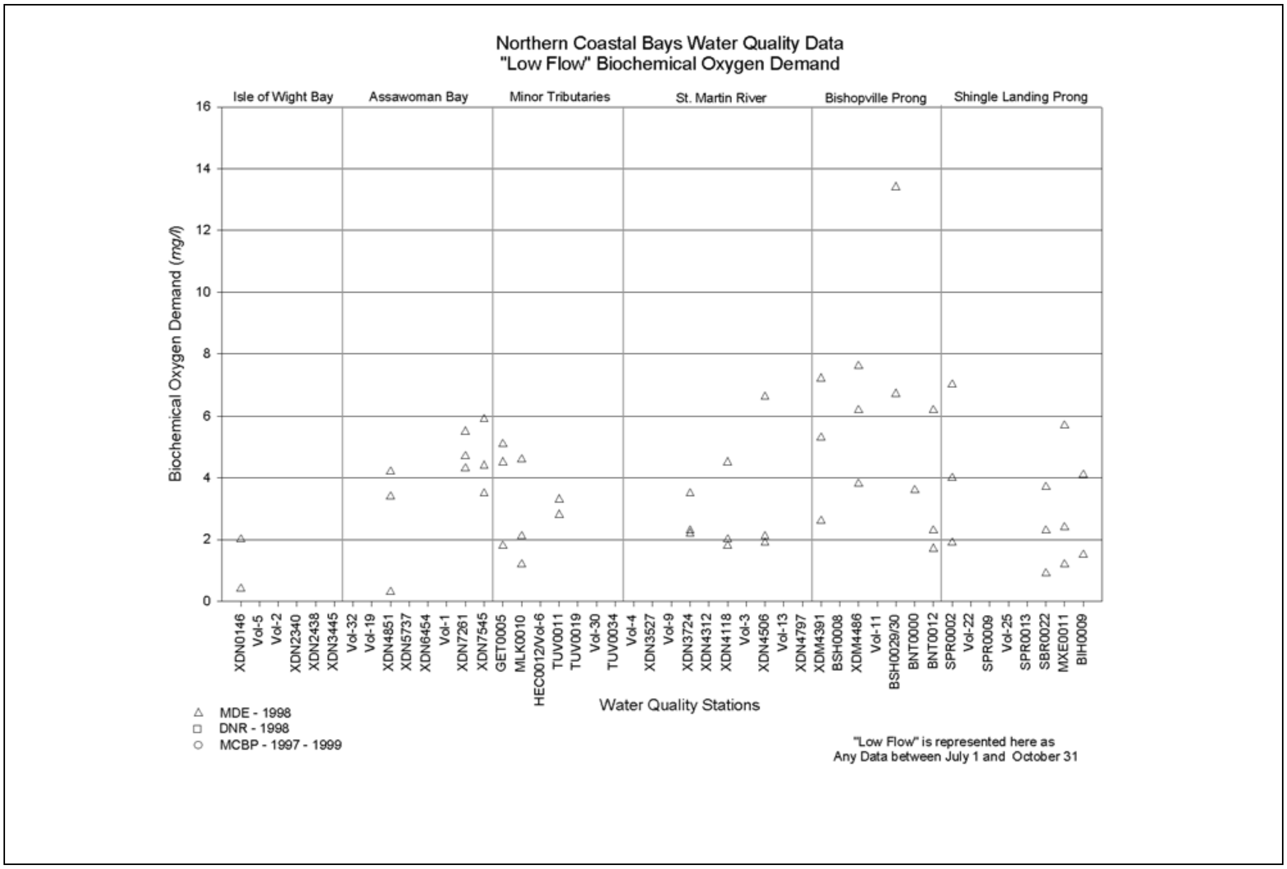


Figure A7: Profile of Biochemical Oxygen Demand Data

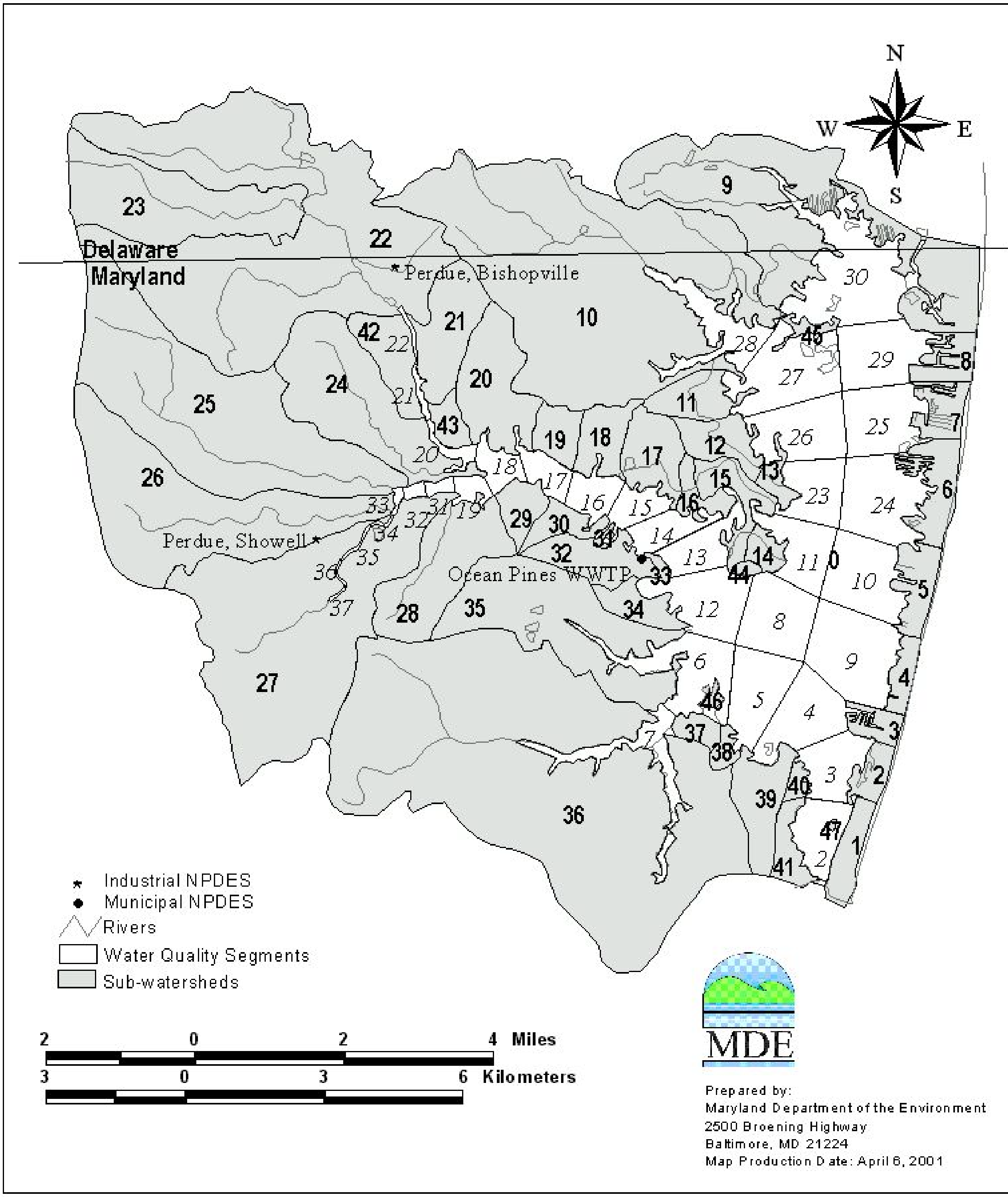


Figure A8: NCBEM Segmentation – Water Quality and Subwatershed

Segment	Volume m^3	Depth m
1	1222560	2.438
2	1204731	0.8382
3	3231668	1.929
4	4046900	1.676
5	2992125	1.423
6	3362040	1.372
7	1534992	0.9144
8	3067720	1.524
9	3367700	1.067
10	1668908	0.701
11	2960180	1.524
12	2677746	1.448
13	2292300	1.524
14	1760385	1.423
15	1228220	1.524
16	1390322	1.402
17	842208	1.219
18	396200	0.3048
19	100004	0.3048
20	90560	0.3048
21	33960	0.3048
22	11320	0.3048
23	3465958	1.728
24	2136865	0.8138
25	1528200	0.762
26	4332096	1.625
27	3894080	1.219
28	2377200	1.067
29	3486560	1.219
30	5634813	1.125
31	54003	0.303
32	43065	0.3
33	31270	0.29
34	7828	0.28
35	1400	0.28
36	668	0.28
37	477	0.28

Table A3: Water Quality Model Segment Volumes and Depths

Table A4: Water Quality Segment Pair Characteristic Lengths, Interfacial Areas, and Dispersion Coefficients

Segment Pairs		Characteristic Length m	Interfacial Area m^2	Dispersion Coefficient m^2/sec
0	1	1530.2	245.1	115.50
1	2	1600.2	383.2	115.50
2	3	1600.2	534.2	115.50
3	4	1371.6	987.1	13.20
4	5	1371.6	2717.3	13.20
4	9	1447.8	766.4	13.20
5	6	1409.7	2159.9	13.20
6	0	1409.7	354.1	13.20
5	8	1066.8	2612.8	13.20
6	7	1600.2	331	13.20
7	0	1216.7	251.5	13.20
6	12	1714.5	1672.2	13.20
8	9	1600.2	1556.1	13.20
8	12	1143	3100.5	13.20
12	13	1028.7	1950.9	11.15
13	14	1028.7	2961.2	11.15
14	15	1028.7	1800	11.15
15	16	1028.7	1248.3	7.00
16	17	1028.7	882.6	7.00
17	18	1028.7	313.5	7.00
18	19	912	175	7.00
19	31	678.5	112.5	7.00
31	32	558.5	87.5	5.00
32	33	551	69.4	5.00
33	34	603	32	5.00
33	0	606	17.7	5.00
34	35	800	7.2	5.00
18	20	2057.4	127.7	5.00
20	21	990.6	46.5	5.00
35	36	850	1.2	1.00
36	37	600	1	1.00
37	0	500	1	1.00
18	20	2057.4	127.7	1.00
20	21	990.6	46.5	1.00
21	22	1257.3	23.2	1.00
22	0	857.8	21.1	1.00
8	11	1524	1393.5	4.44
9	10	1676.4	1335.4	4.44
10	11	1371.6	1410.9	4.44
10	24	1676.4	856.4	4.44
11	23	1676.4	2926.4	4.44
23	24	1409.7	2612.8	4.44
23	26	1600.2	3332.8	3.67
24	25	1676.4	522.6	3.67
25	26	1524	1544.5	3.67
26	27	1333.5	3800.2	3.67
25	29	1676.4	1103.2	3.67
27	29	1905	2235.4	3.67
27	28	1295.4	2177.3	3.19
29	30	2026.9	3170.2	3.19
27	30	2187.1	423.7	3.19
30	0	1290.1	289.3	3.19
28	0	2310.4	1737.3	3.19

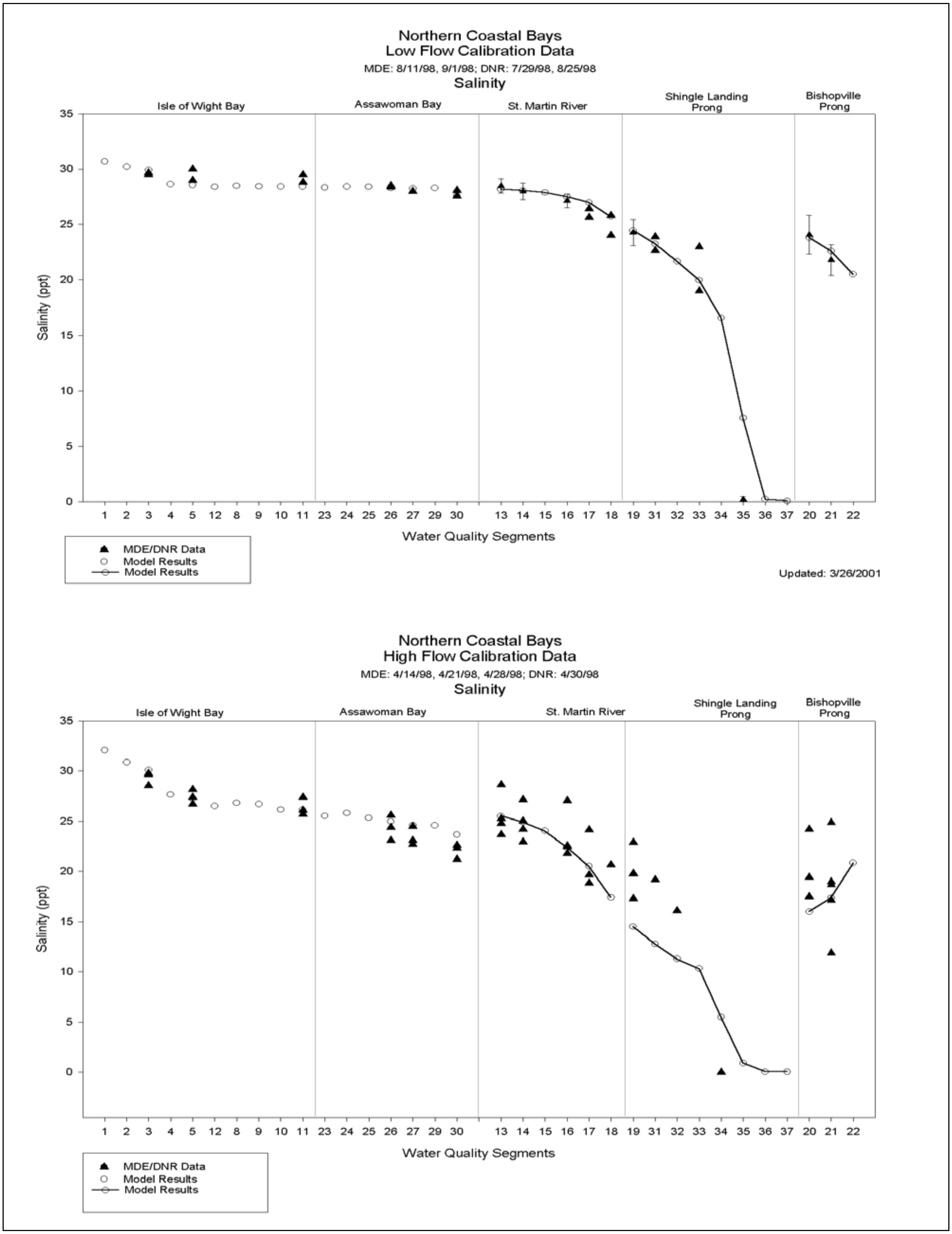


Figure A9: Low Flow and High Flow Calibrations of the Model for Salinity

Table A5: Freshwater flows to the Northern Coastal Bays

Flows to Water Quality Segment	Sub-watersheds	Area km^2	Low Flows cfs	High Flows cfs	Average Annual cfs
2	1,41,47	1.966	0.117	0.899	0.914
3	2,40	0.968	0.058	0.443	0.450
4	3,39	2.852	0.170	1.304	1.326
5	38	0.294	0.017	0.134	0.136
6	35,37,46	8.167	0.487	3.735	3.797
7	36	34.966	2.083	15.992	16.257
9	4	0.710	0.042	0.325	0.330
10	5	1.281	0.076	0.586	0.595
11	14	0.561	0.033	0.257	0.261
12	34,44	1.140	0.068	0.521	0.530
14	15,16,32, 33	3.982	0.237	1.821	1.851
15	17,31	2.063	0.123	0.943	0.959
16	18,30	2.295	0.137	1.050	1.067
17	19,29	2.109	0.126	0.964	0.980
18	20	3.609	0.215	1.651	1.678
19	28	4.609	0.275	2.108	2.143
20	24,43	7.547	0.450	3.452	3.509
21	21,42	4.864	0.290	2.225	2.262
22	22,23	31.364	1.869	14.345	14.582
23	13	0.459	0.027	0.210	0.214
24	6	1.643	0.098	0.751	0.764
25	7	1.008	0.060	0.461	0.469
26	12	1.367	0.081	0.625	0.635
27	11,45	1.689	0.101	0.772	0.785
28	10	24.139	1.438	11.040	11.223
29	8	0.889	0.053	0.407	0.413
30	9	12.073	0.719	5.522	5.613
33	25,26	26.581	1.584	12.157	12.358
37	27	16.656	0.992	7.618	7.744

Table A6: 1998 Point Source Loads used in the High Flow and Low Flow Calibrations of the NCBEM

	FLOW	NH3	NO23	TON	TKN	TN	PO4	TP	OP	CBODu	DO
High Flow Loads	*mgd*	*kg/d*	*kg/d*	*kg/d*	*kg/d*	*kg/d*	*kg/d*	*kg/d*	*kg/d*	*kg/d*	*kg/d*
Ocean Pines WWTP	0.803	0.61	3.65	2.98	3.59	7.24	3.65	3.96	0.30	11.16	22.83
Perdue Farm Inc., Showell	0.430	39.17	1.09	7.78	46.95	48.04	0.11	0.57	0.46	32.41	10.76
Low Flow Loads											
Ocean Pines WWTP	0.963	0.57	2.52	2.56	3.12	5.64	1.30	1.66	0.37	16.48	24.66
Perdue Farm Inc., Showell	0.593	1.41	4.09	2.66	4.08	8.17	0.05	0.23	0.19	15.84	13.50

Table A7: Water Quality Monitoring Stations used to Estimate Nonpoint Source Boundary Concentrations

Water Quality Segments	Water Quality Monitoring Stations	Secondary Monitoring Stations*
1	XDN0146	
2	XDN0146	
3	Vol-5	TUV0034
4	Vol-5	TUV0034
5	Vol-5	TUV0034
6	TUV0034	
7	TUV0034	
8	none	
9	Vol-2	TUV0034
10	Vol-32	TUV0034
11	GET0005	
12	Vol-7	TUV0034
13	none	
14	Vol-9	BNT0012
15	Vol-3	BNT0012
16	Vol-3	BNT0012
17	Vol-3	BNT0012
18	Vol-13	BNT0012
19	TUV0034	
20	BNT0012	
21	BNT0012	
22	BSH0029	
23	GET0005	
24	Avg (Vol-32,Vol-19)	GET0005
25	Vol-19	GET0005
26	GET0005	
27	GET0005	
28	GET0005	
29	Vol-19	GET0005
30	Avg (XDN7545,XDN7261, Vol-1)	Avg (XDN7545,XDN7261)
33	Avg (BIH0009,MXE0011)	
36	Avg (BIH0009,MXE0011)	

* No ortho-phosphate, BOD, dissolved oxygen, organic nitrogen, or organic phosphorus data measured at the MCBP volunteer stations, thus complimentary data necessary to estimate other parameters. Addidionally some stations did not have ammonia or nitrate/ nitrite data.

Table A8: Low Flow Nonpoint Source Loads and Concentrations used in the Calibration of the Model

Water Quality Segment	Flow *cfs*	NH_3 *kg/d*	NO23 *kg/d*	PO_4 *kg/d*	CHLA *ug/l*	CBOD *mg/l*	DO *mg/l*	TON *kg/d*	TOP *kg/d*
1 (all mg/l)		0.031	0.012	0.025	6.355	2.667	6.100	0.406	0.026
2	0.1171	0.883	2.913	0.074	6.355	2.667	6.100	0.615	0.204
3	0.0577	0.924	3.252	0.082	5.340	5.250	4.973	0.592	0.213
4	0.1699	1.426	5.263	0.141	5.340	5.250	4.973	1.004	0.335
5	0.0175	1.273	4.290	0.100	5.340	5.250	4.973	0.745	0.288
6	0.4866	1.648	6.959	0.220	1.080	5.250	4.973	1.487	0.410
7	2.0833	1.292	10.605	0.501	1.080	5.250	4.973	3.079	0.457
8	0.0000	1.368	4.557	0.104	0.000	0.000	0.000	0.780	0.308
9	0.0423	1.928	6.548	0.155	2.640	5.250	4.973	1.147	0.438
10	0.0763	1.474	4.910	0.128	98.000	5.250	4.973	0.932	0.341
11	0.0334	1.048	3.489	0.081	14.578	5.250	6.250	0.654	0.240
12	0.0679	1.381	4.803	0.118	22.000	5.250	4.973	0.864	0.317
14	0.2372	0.649	2.020	0.095	23.800	7.083	5.750	0.798	0.178
15	0.1229	0.532	1.764	0.065	37.467	7.083	5.750	0.536	0.140
16	0.1367	0.562	1.863	0.071	37.467	7.083	5.750	0.579	0.150
17	0.1256	0.480	1.590	0.062	37.467	7.083	5.750	0.511	0.129
18	0.2150	0.585	1.751	0.078	41.267	7.083	5.750	0.662	0.137
19	1.1926	0.266	1.716	0.073	1.080	5.250	4.973	0.460	0.082
20	0.4496	0.300	0.587	0.092	3.427	7.083	5.750	0.858	0.078
21	0.2898	0.193	0.378	0.059	3.427	7.083	5.750	0.553	0.051
22	1.8687	0.375	1.852	0.560	79.993	22.333	4.050	8.940	0.762
23	0.0274	0.962	3.203	0.075	14.578	5.250	6.250	0.595	0.220
24	0.0979	1.735	5.779	0.138	98.000	5.250	6.250	1.162	0.405
25	0.0600	1.407	4.683	0.110	14.578	5.250	6.250	0.903	0.324
26	0.0814	1.390	4.624	0.110	14.578	5.250	6.250	0.929	0.322
27	0.1006	1.858	6.184	0.146	14.578	5.250	6.250	1.229	0.430
28	1.4382	1.406	4.631	0.177	14.578	5.250	6.250	3.222	0.478
29	0.0530	1.480	4.926	0.115	14.578	5.250	6.250	0.933	0.339
30	0.7193	2.921	9.663	0.257	21.016	8.542	5.725	4.006	0.765
31	0.0000	0.102	0.339	0.008	0.000	0.000	0.000	0.058	0.023
32	0.0000	0.081	0.271	0.006	0.000	0.000	0.000	0.046	0.018
33	1.5837	0.607	2.859	0.170	2.723	5.708	5.800	2.152	0.299
34	0.0000	0.022	0.073	0.002	0.000	0.000	0.000	0.013	0.005
37	0.9924	0.346	1.678	0.104	2.723	5.708	5.800	1.329	0.179

Table A9: High Flow Nonpoint Source Loads and Concentrations used in the Calibration of the Model

Water Quality Segment	Flow *cfs*	NH_3 *kg/d*	NO23 *kg/d*	PO_4 *kg/d*	CHLA *ug/l*	CBOD *mg/l*	DO *mg/l*	TON *kg/d*	TOP *kg/d*
1 (all mg/l)		0.008	0.002	0.010	4.934	3.333	7.867	0.493	0.025
2	0.8990	0.892	3.731	0.088	4.934	3.333	7.867	1.585	0.251
3	0.4427	0.951	6.720	0.107	1.699	3.333	8.600	0.558	0.233
4	1.3042	1.504	14.273	0.217	1.699	3.333	8.600	0.906	0.395
5	0.1343	1.281	6.269	0.108	1.699	3.333	8.600	0.735	0.294
6	3.7354	1.871	30.489	0.435	1.863	3.333	8.600	1.204	0.581
7	15.9924	2.246	105.963	1.422	1.863	3.333	8.600	1.868	1.188
8	0.0000	1.368	5.834	0.104	0.000	0.000	0.000	0.780	0.308
9	0.3248	1.947	10.260	0.174	4.360	3.333	8.600	1.122	0.453
10	0.5857	1.519	10.007	0.162	12.200	3.333	8.600	0.888	0.367
11	0.2566	1.094	5.548	0.090	19.587	3.333	10.500	0.960	0.256
12	0.5212	1.412	9.160	0.148	1.863	3.333	8.600	0.824	0.340
14	1.8211	1.685	11.080	0.139	6.800	3.333	9.300	3.603	0.277
15	0.9434	1.088	6.655	0.088	16.930	3.333	9.300	1.989	0.192
16	1.0497	1.180	7.277	0.096	16.930	3.333	9.300	2.196	0.207
17	0.9645	1.048	6.531	0.085	16.930	3.333	9.300	1.997	0.182
18	1.6507	1.420	9.587	0.118	47.200	3.333	9.300	3.205	0.227
19	3.0344	0.392	14.374	0.195	1.863	3.333	8.600	0.301	0.178
20	3.4517	2.047	16.285	0.176	4.143	3.333	9.300	6.175	0.266
21	2.2248	1.319	10.471	0.113	4.143	3.333	9.300	3.980	0.171
22	14.3448	2.331	52.764	0.955	9.303	3.333	9.433	27.480	1.756
23	0.2101	0.999	4.986	0.082	19.587	3.333	10.500	0.845	0.233
24	0.7514	1.882	10.618	0.164	9.760	3.333	10.500	2.059	0.451
25	0.4609	1.488	7.937	0.126	7.320	3.333	10.500	1.454	0.352
26	0.6250	1.500	8.554	0.131	19.587	3.333	10.500	1.676	0.360
27	0.7724	1.995	11.172	0.173	19.587	3.333	10.500	2.151	0.477
28	11.0404	3.357	52.444	0.554	19.587	3.333	10.500	16.403	1.150
29	0.4067	1.552	8.020	0.129	7.320	3.333	10.500	1.419	0.364
30	5.5219	3.071	17.591	0.654	14.013	3.333	8.467	6.501	0.678
31	0.0000	0.102	0.434	0.008	0.000	0.000	0.000	0.058	0.023
32	0.0000	0.081	0.347	0.006	0.000	0.000	0.000	0.046	0.018
33	12.1574	4.128	37.997	0.776	5.498	3.333	8.875	18.753	1.254
34	0.0000	0.022	0.073	0.002	0.000	0.000	0.000	0.013	0.005
37	7.6179	2.552	23.664	0.484	5.498	3.333	8.875	11.731	0.778

Table A10: Comparison of Average Annual Total Nitrogen Loads using Three Different Sets of Loading Rates

Total Nitrogen (lb/yr) by Sub-Basin	Sub-Watershed number	Watershed Area Acres	DNR/USGS Study	CBP (seg. 430)	UMCES Study	In-Stream Data
Assawoman	9	2,983	36,965	32,705	17,784	5,787
Greys Creek	10	5,965	125,781	75,624	49,275	27,674
Manklin Creek	35+37+46	2,018	14,997	19,153	9,607	2,368
Herring + Turville Creeks	36	8,640	98,078	75,826	46,564	20,327
Middle + Birch Branches	25+26	6,568	162,775	91,745	61,249	16,359
Bishopville Prong	22+23	7,750	163,290	102,172	64,438	23,419
TOTAL		33,925	601,886	397,224	248,917	95,933

Table A11: Comparison of Average Annual Total Phosphorus Loads using Three Different Sets of Loading Rates

Total Phosphorus (lb/yr) by Sub-Basin	Sub-Watershed number	Watershed Area Acres	DNR/USGS Study	CBP (seg. 430)	UMCES Study	In-Stream Data
Assawoman	9	2,983	6,187	2,164	2,216	272
Greys Creek	10	5,965	20,831	5,392	6,268	603
Manklin Creek	35+37+46	2,018	2,343	1,055	1,184	139
Herring + Turville Creeks	36	8,640	15,877	4,852	5,599	737
Middle + Birch Branches	25+26	6,568	26,976	6,667	7,878	706
Bishopville Prong	22+23	7,750	27,219	7,344	8,233	1,130
TOTAL		33,925	99,433	27,474	31,378	3,588

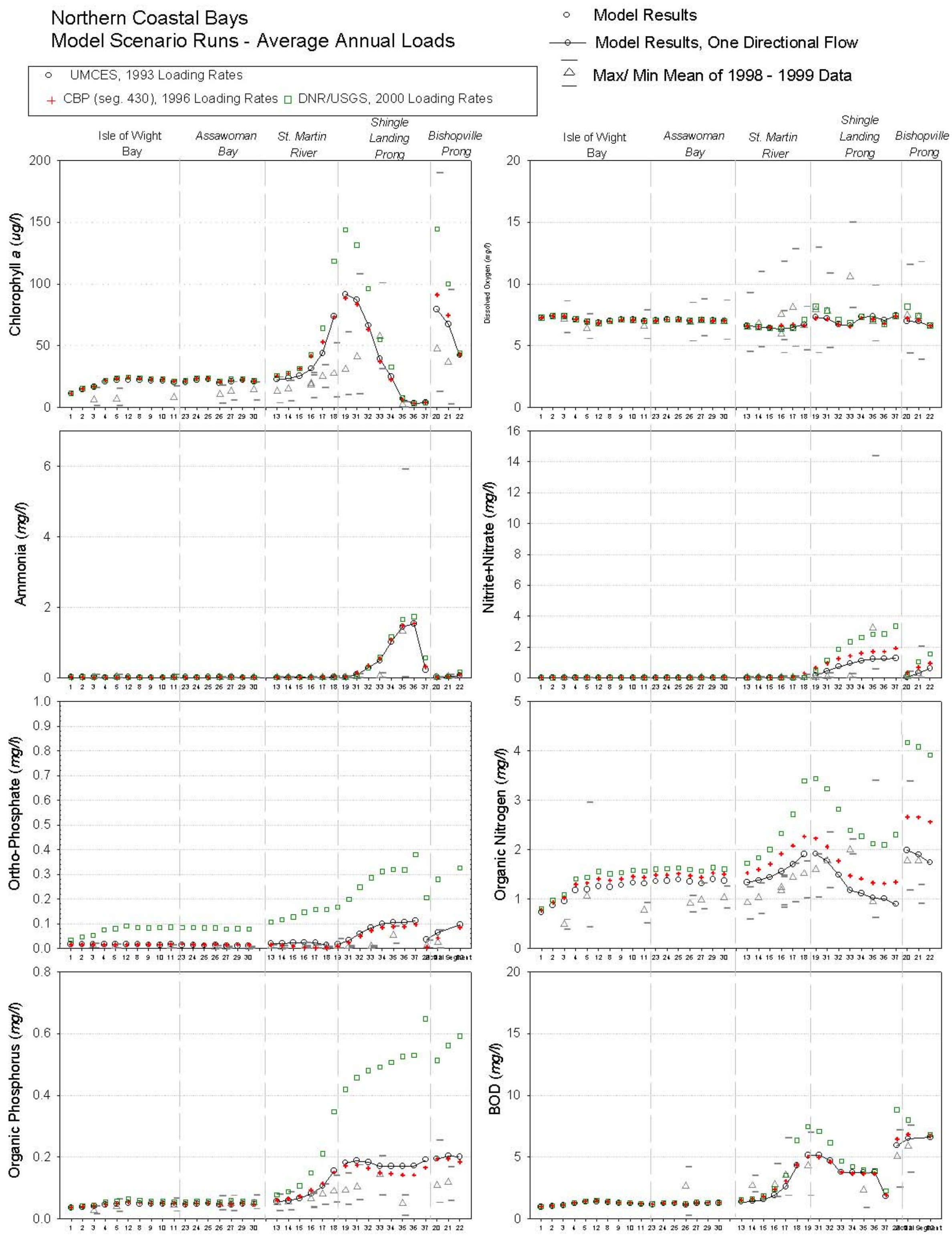


Figure A10: Model Results for Average Annual Flow conditions using DNR/USGS, CBP, and UMCES Loading Rates

Table A12: Comparison of Average Annual Urban Total Nitrogen and Total Phosphorus Loading Rates

Total Nitrogen (lb/acre-year)	Base	Average Storm	Total
Hamilton Ave (Balt. City, 2000)	5.00	5.00	9.99
Radecke Ave (Balt City, 2000)	1.71	6.66	8.42
Baltimore City Average	3.36	5.83	9.21
Back River (Balt. Co., 2000)	3.51	5.93	9.43
UMCES, 1993			4.44
U.S.EPA/CBP (seg. 430),1996			9.98
NCBEM			7.56
Total Phosphorus (lb/acre-year)	Base	Average Storm	Total
Hamilton Ave (Balt. City, 2000)	0.10	0.41	0.52
Radecke Ave (Balt City, 2000)	0.04	0.57	0.62
Baltimore City Average	0.07	0.49	0.57
Back River (Balt. Co., 2000)	0.11	0.55	0.66
UMCES, 1993			0.49
U.S.EPA/CBP (seg. 430),1996			0.45
NCBEM			0.55

Table A13: Estimated Current Average Annual Nonpoint Source Loads and Concentrations

Water Quality Segment	Flow *cfs*	NH_3 *kg/d*	NO23 *kg/d*	PO_4 *kg/d*	CHLA *ug/l*	CBOD *mg/l*	DO *mg/l*	TON *kg/d*	TOP *kg/d*
1 (all mg/l)		0.0367	0.009	0.016	4.990	2.000	6.972	0.456	0.027
2	0.914	1.143	3.792	0.202	4.990	2.000	6.972	4.113	0.417
3	0.450	1.028	3.931	0.115	4.678	6.333	6.831	2.025	0.279
4	1.326	1.523	9.987	0.436	4.678	6.333	6.831	1.783	0.549
5	0.136	1.279	5.707	0.124	4.678	6.333	6.831	0.796	0.305
6	3.797	1.861	16.096	0.983	1.973	6.333	6.831	3.199	0.966
7	16.257	2.365	49.645	4.157	1.973	6.333	6.831	11.710	3.112
8	0.000	1.368	5.834	0.104	0.000	0.000	0.000	0.780	0.308
9	0.330	1.961	9.481	0.217	7.387	6.333	6.831	1.412	0.483
10	0.595	1.533	8.251	0.221	24.059	6.333	6.831	1.324	0.409
11	0.261	1.088	4.817	0.111	22.004	6.333	8.067	1.039	0.303
12	0.530	1.404	6.937	0.202	19.043	6.333	6.831	1.050	0.378
14	1.851	1.276	5.670	0.392	13.444	5.667	7.631	2.885	0.559
15	0.959	0.922	4.066	0.241	27.352	5.667	7.631	1.793	0.365
16	1.067	1.009	4.456	0.280	27.352	5.667	7.631	2.026	0.417
17	0.980	0.930	4.121	0.277	27.352	5.667	7.631	1.990	0.401
18	1.678	1.551	6.996	0.643	34.330	5.667	7.631	4.455	0.844
19	2.143	0.490	9.673	0.861	1.973	6.333	6.831	2.266	0.648
20	3.509	2.250	10.546	1.225	3.565	5.667	7.631	8.525	1.498
21	2.262	1.440	6.724	0.781	3.565	5.667	7.631	5.455	0.955
22	14.582	2.976	23.569	3.659	36.923	16.750	7.783	53.702	6.594
23	0.214	0.984	4.301	0.092	19.757	6.333	8.067	0.808	0.256
24	0.764	1.896	8.741	0.205	21.688	6.333	8.067	2.607	0.549
25	0.469	1.508	6.871	0.156	22.004	6.333	8.067	1.891	0.422
26	0.635	1.501	6.904	0.196	22.004	6.333	8.067	2.024	0.508
27	0.785	2.000	9.159	0.254	22.004	6.333	8.067	2.613	0.663
28	11.223	4.365	31.485	2.547	22.004	6.333	8.067	32.368	5.614
29	0.413	1.568	7.078	0.155	22.004	6.333	8.067	1.804	0.426
30	5.613	3.145	12.487	0.884	1.496	7.861	7.221	23.430	2.749
31	0.000	0.102	0.434	0.008	0.000	0.000	0.000	0.058	0.023
32	0.000	0.081	0.347	0.006	0.000	0.000	0.000	0.046	0.018
33	12.358	6.881	41.564	3.629	3.775	4.556	7.285	28.149	6.197
34	0.000	0.022	0.073	0.002	0.000	0.000	0.000	0.013	0.005
37	7.744	4.008	24.270	2.113	3.775	4.556	7.285	16.511	3.604

Table A14: Environmental Parameters used in the Low Flow and High Flow Calibrations of the Model

Segment	Temperature (^oC)		Salinity (ppt)		Extinction Coeff. (m^{-1})		FNH4	FPO4	SOD
	Low Flow	High flow	Low Flow	High flow	Low Flow	High flow	mg N/ m^2d	mg P/ m^2d	g O_2/ m^2d
1	24.5	11.3	30.4	29.5	2.3	1.8	26.0	0.14	0.8
2	24.5	11.3	30.4	29.5	2.3	1.8	26.0	0.14	0.8
3	25.0	11.7	29.6	29.1	2.3	1.6	26.0	1.00	1.0
4	25.9	12.7	29.5	28.2	2.8	1.6	26.0	1.00	1.0
5	26.9	13.7	29.5	27.4	3.5	1.5	26.0	1.00	1.0
6	26.9	15.1	29.1	26.4	3.9	2.7	90.0	6.00	2.5
7	27.6	14.9	28.6	26.4	4.9	2.4	80.0	7.00	2.5
8	26.9	13.7	29.5	27.4	3.5	1.5	26.0	1.00	1.0
9	26.9	13.7	29.5	27.4	3.9	1.5	26.0	1.00	1.0
10	27.3	14.3	29.2	26.0	4.9	1.7	26.0	1.00	1.0
11	27.3	14.7	28.5	24.3	3.5	2.1	26.0	1.00	1.0
12	27.2	14.7	28.5	25.1	4.3	1.6	26.0	0.60	1.0
13	27.2	14.7	28.5	25.1	4.3	1.6	26.0	0.60	1.7
14	27.5	15.7	28.0	24.4	4.3	2.1	28.0	0.60	1.7
15	27.5	15.8	27.4	24.0	4.6	2.2	28.0	0.60	1.7
16	27.8	15.9	27.1	23.7	5.2	2.0	28.0	0.60	1.7
17	28.2	16.5	26.0	20.4	6.5	2.4	45.0	2.00	1.7
18	28.4	17.1	24.9	20.7	4.3	3.3	54.0	3.50	2.0
19	28.9	17.1	24.3	19.9	6.0	3.3	58.0	7.50	2.0
20	28.7	17.5	24.1	20.0	4.6	3.9	50.0	4.50	2.0
21	29.4	18.7	21.7	18.0	5.6	5.0	50.0	5.00	2.0
22	27.8	14.9	6.4	0.6	9.8	7.0	50.0	5.00	2.0
23	27.3	14.5	28.8	25.2	4.3	1.9	26.0	1.00	1.0
24	27.3	14.5	28.8	25.1	4.3	1.9	26.0	1.00	1.0
25	27.3	14.7	28.5	24.3	4.9	2.1	26.0	1.00	1.0
26	27.3	14.7	28.5	24.3	4.9	2.1	26.0	1.00	1.0
27	27.3	14.7	28.5	24.3	4.9	2.1	26.0	1.00	1.0
28	25.3	16.0	10.0	0.0	5.6	2.1	26.0	1.00	1.0
29	27.7	15.1	27.9	22.0	5.6	2.1	26.0	1.00	1.0
30	27.7	15.1	27.9	22.0	5.6	2.1	26.0	1.00	1.0
31	29.6	17.5	23.3	19.2	5.6	6.5	75.0	8.50	2.0
32	31.1	19.7	21.0	16.1	6.5	6.5	95.0	10.00	2.0
33	27.0	19.7	10.0	16.1	6.5	6.5	110.0	11.00	2.0
34	27.0	14.1	10.0	0.0	6.5	7.0	85.0	10.00	2.0
35	24.1	14.1	0.2	0.0	7.0	7.0	30.0	6.50	1.5
36	24.1	14.1	0.2	0.0	7.0	7.0	14.5	5.00	1.5
37	24.1	14.1	0.2	0.0	7.0	7.0	14.5	5.00	1.5

	Low Flow	High flow	
Solar Radiation	432.	396.	langleys
Photoperiod	0.56	0.54	fraction of a day

Table A15: Settling Velocities used in the NCBEM

	Water Quality Segments	Organic/ Inorganic Settling Velocities (m/s)	Phytoplankton Settling Velicity (m/s)
Isle of Wight Bay	1 - 5, 8 -12	2.0 e-7	8.0 e-7
Assawoman Bay	23 - 27, 29, 30	2.0 e-7	7.0 e-7
Tidal Tributaries	6, 7, 28	3.0 e-7	1.0 e-6
St. Martin River	13 - 18	3.0 e-7	1.0 e-6
Shingle Landing Prong	19 - 33	3.0 e-7	1.5 e-6
Bishopville Prong	20 - 22	3.0 e-7	1.5 e-6
Church Branch	34 - 37	1.0 e-7	1.0 e-7

Table A16: EUTRO5 Kinetic Coefficients

Constant	Code	Value
Nitrification rate	K12C	0.07 *day*-1 at 20^o C
temperature coefficient	K12T	1.08
Denitrification rate	K20C	0.01 *day*-1 at 20^o C
temperature coefficient	K20T	1.08
Saturated growth rate of phytoplankton	K1C	1.9 *day*-1 at 20^o C
temperature coefficient	K1T	1.06
Endogenous respiration rate	K1RC	0.125 *day*-1 at 20^o C
temperature coefficient	K1RT	1.045
Nonpredatory phytoplankton death rate	K1D	0.02 *day*-1
Phytoplankton Stoichometry		
Oxygen-to-carbon ratio	ORCB	2.67 $mg\ O_2/\ mg\ C$
Carbon-to-chlorophyll ratio	CCHL	30
Nitrogen-to-carbon ratio	NCRB	0.25 *mg N/mg C*
Phosphorus-to-carbon ratio	PCRB	0.025 $mg\ PO_4\text{-}P/\ mg\ C$
Half-saturation constants for phytoplankton growth		
Nitrogen	KMNG1	0.025 *mg* N / L
Phosphorus	KMPG1	0.001 *mg* P / P
Fraction of dead phytoplankton recycled to organic		
nitrogen	FON	1.0
phosphorus	FOP	1.0
Light Formulation Switch	LGHTS	1 = Di Toro
Saturation light intensity for phytoplankton	IS1	350. *Ly/day*
BOD deoxygenation rate	KDC	0.07 *day*-1 at 20^o C
temperature coefficient	KDT	1.05
Mineralization rate of dissolved organic nitrogen	K71C	0.003 *day*-1
temperature coefficient	K71T	1.08
Mineralization rate of dissolved organic phosphorus	K58C	0.07 *day*-1
temperature coefficient	K58T	1.00

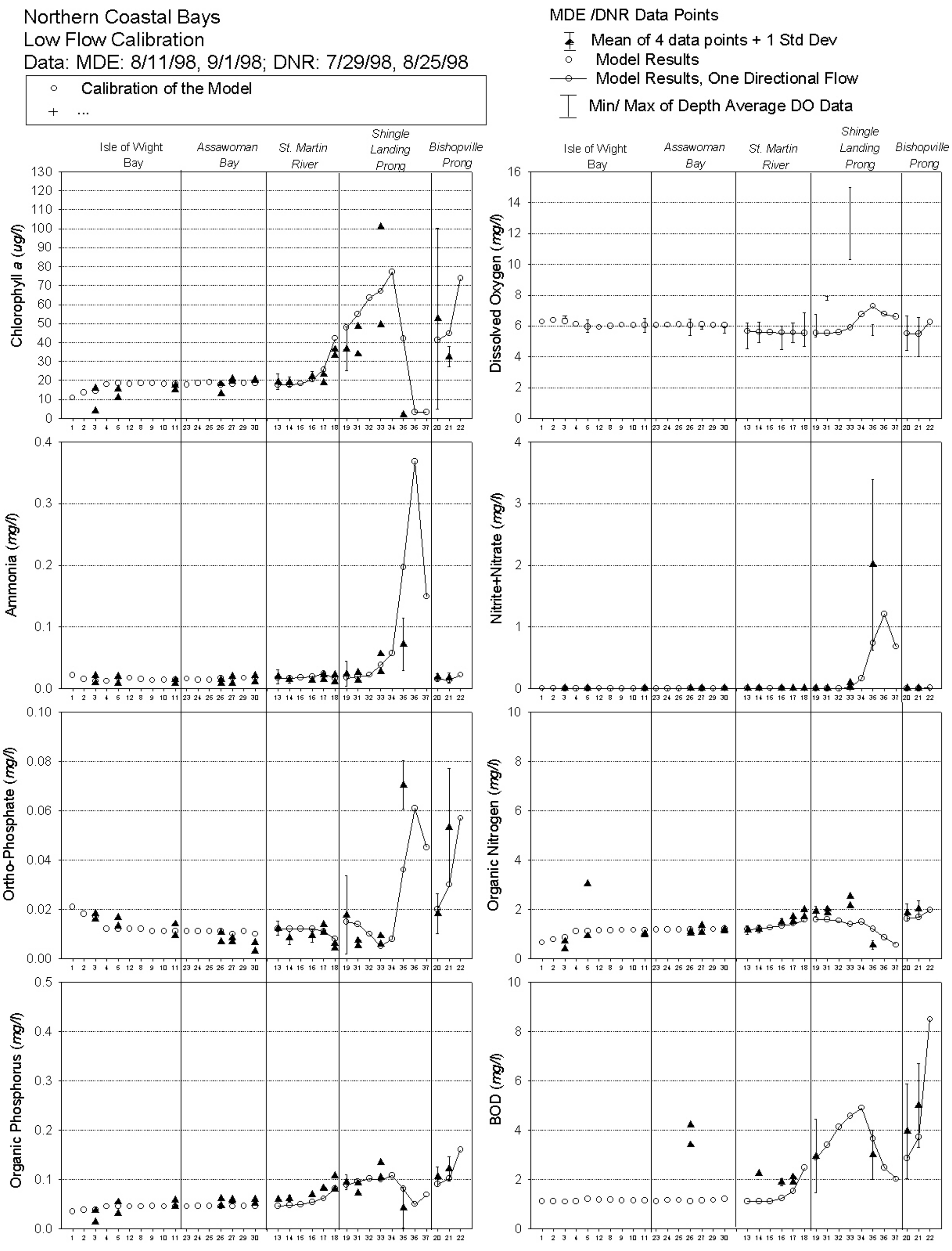


Figure A11: Low Flow Calibration of the Model

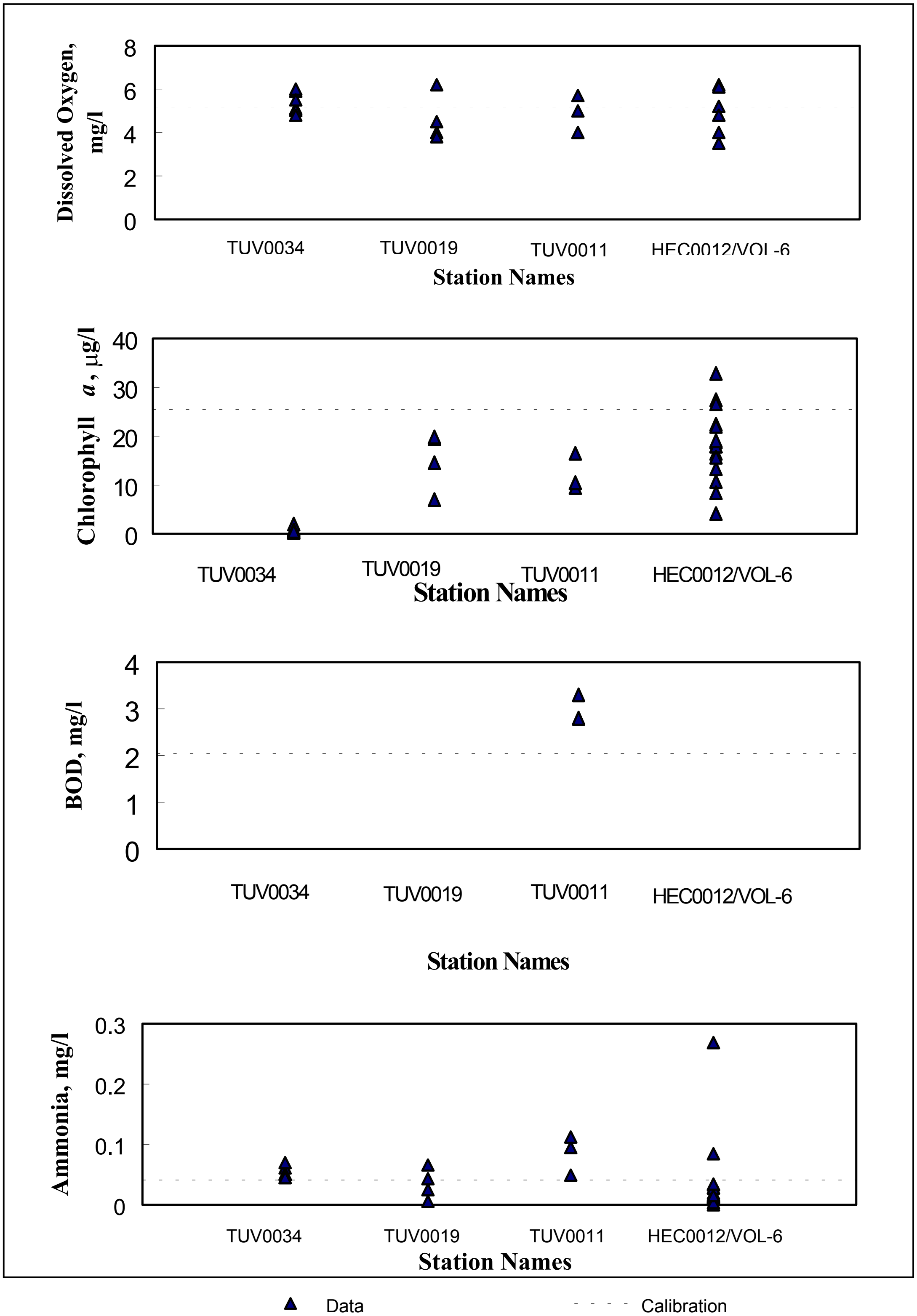


Figure A12: Low Flow Calibration of Dissolved oxygen, Chlorophyll *a*, Biochemical

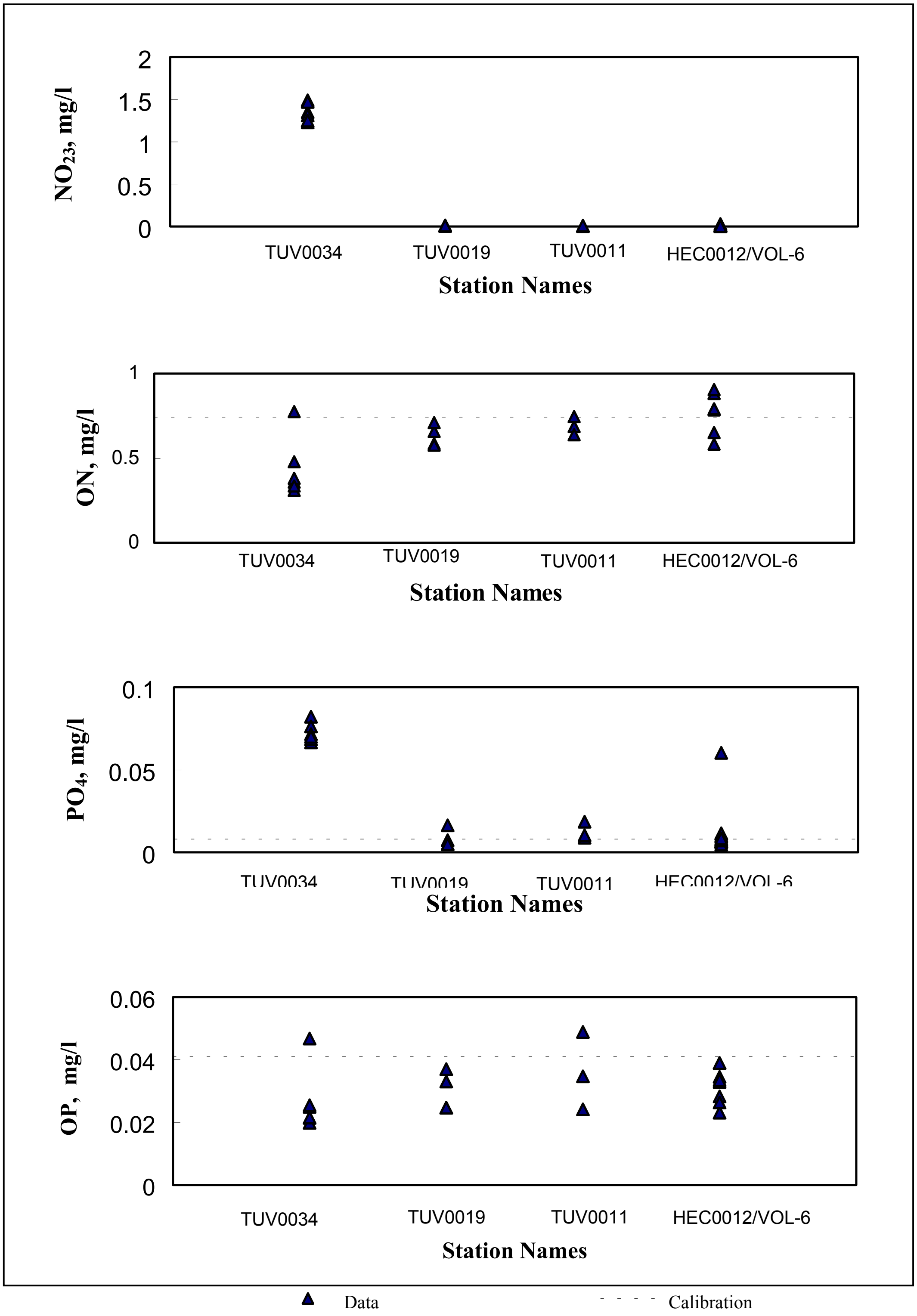


Figure A13: Low Flow Calibration of Nitrate & Nitrite (NO23), Organic Nitrogen (ON), Inorganic Phosphorus (PO4), and Organic Phosphorus (OP) in Turville & Herring Creeks

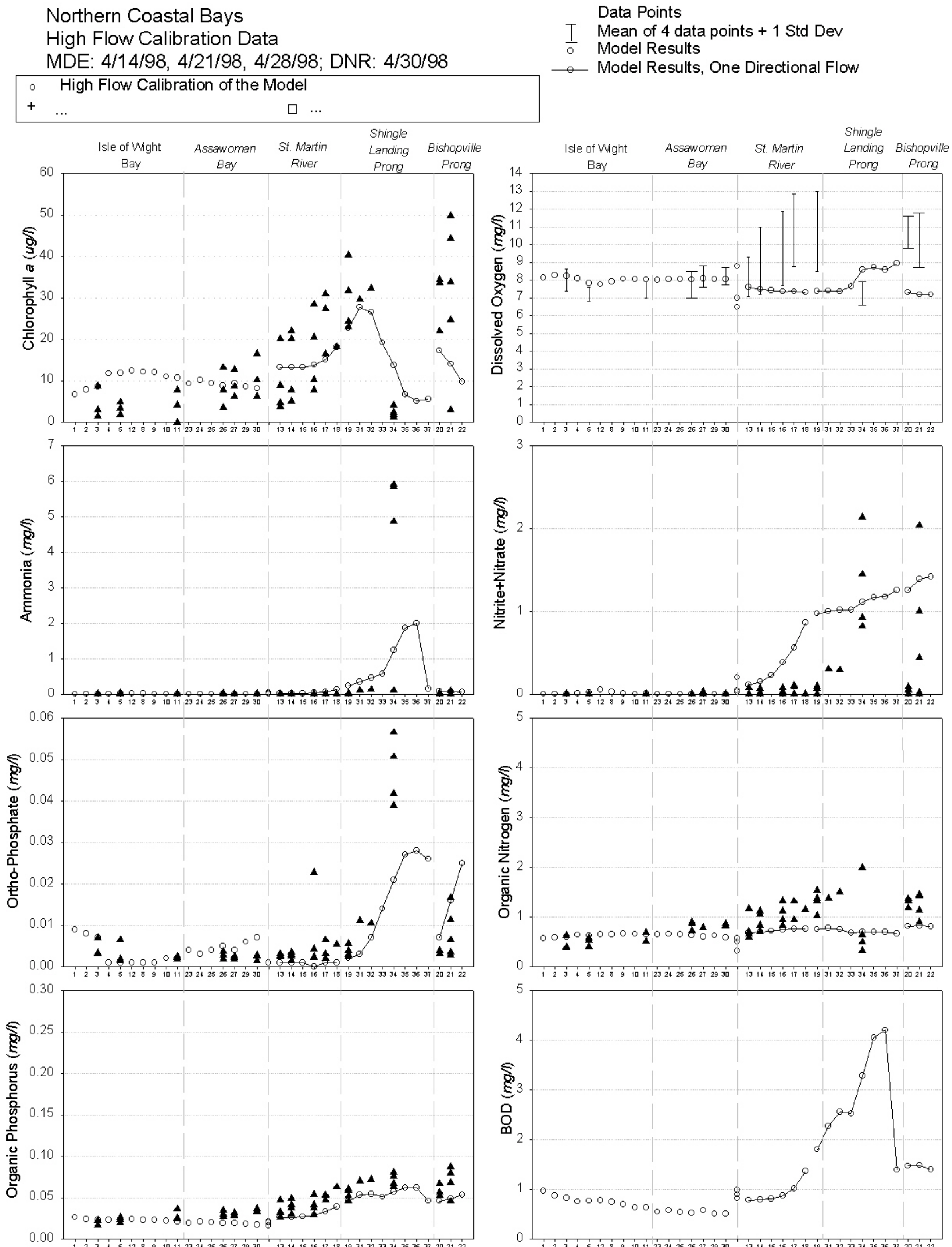


Figure A14: High Flow Calibration of the Model

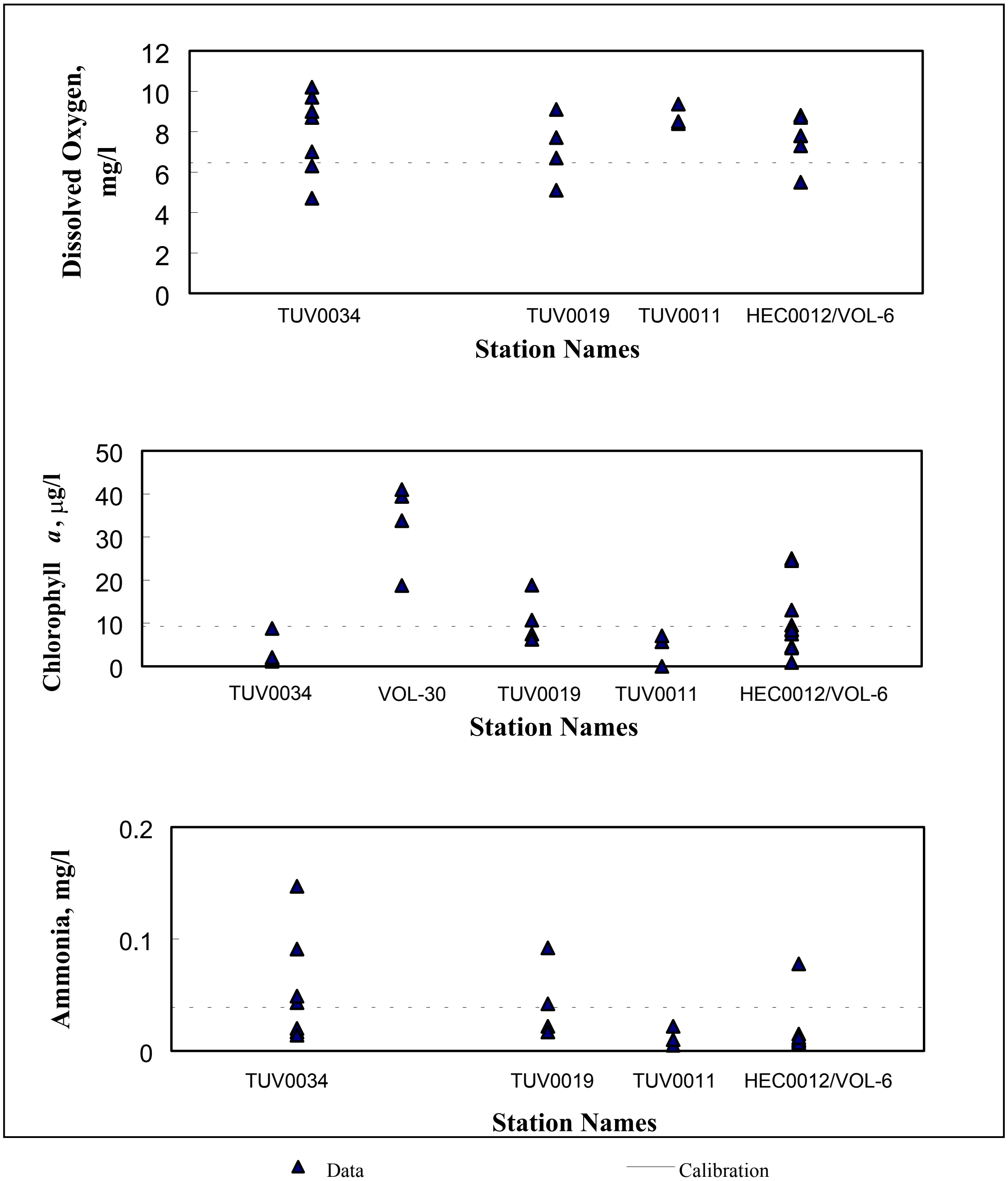


Figure A15: High Flow Calibration of Dissolved oxygen, Chlorophyll *a*, and Ammonia in Turville & Herring Creeks

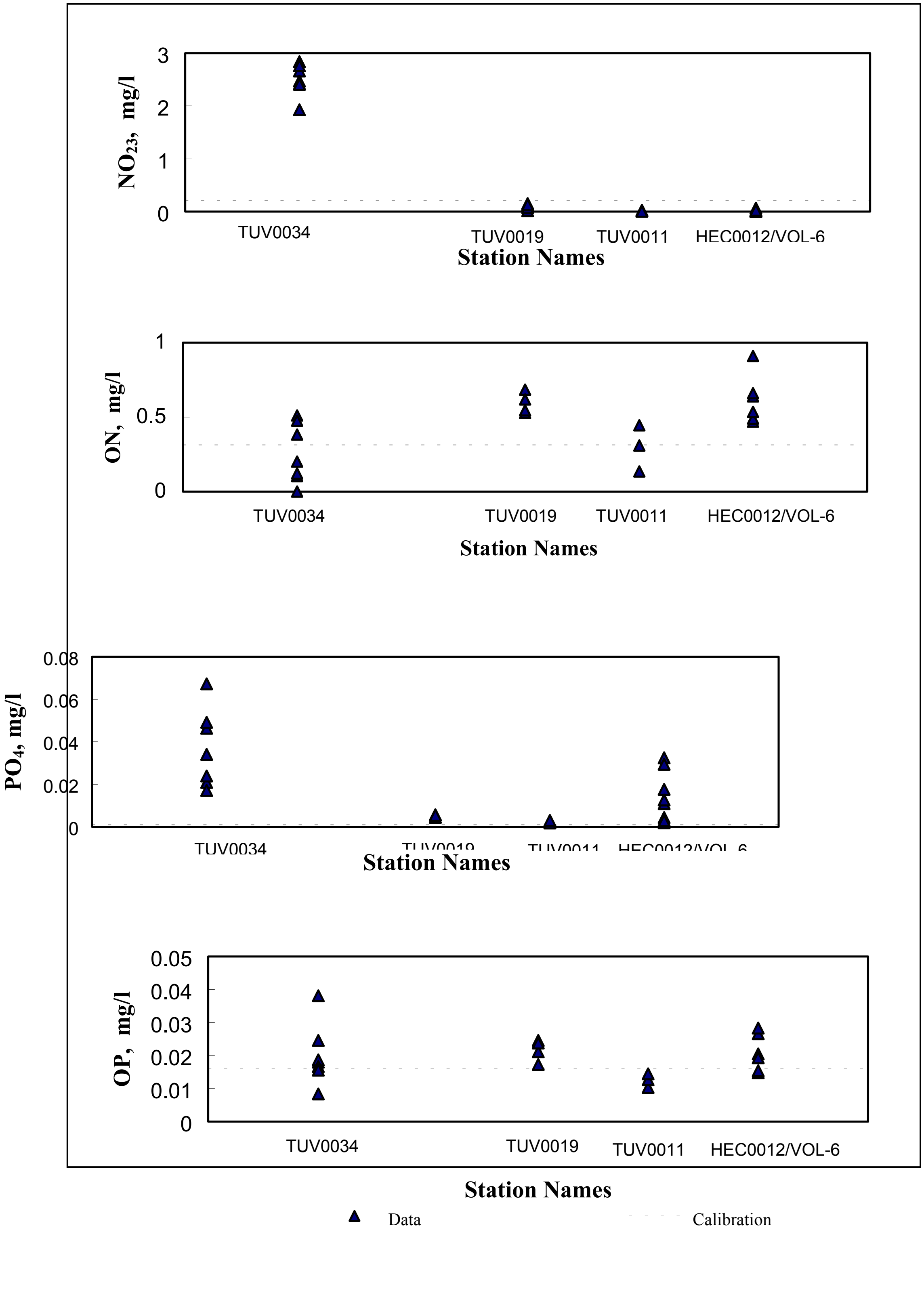


Figure A16: High Flow Calibration of Nitrate & Nitrite (NO23), Organic Nitrogen (ON),

Inorganic Phosphorus (PO4), and Organic Phosphorus (OP) in Turville & Herring Creeks

Table A17: Maximum Point Source Loads used in Scenario 1 & Scenario 3 (Baseline Scenario)

Low Flow *Baseline Loads*	FLOW *mgd*	NH3 *kg/d*	NO23 *kg/d*	TON *kg/d*	TN *kg/d*	PO4 *kg/d*	OP *kg/d*	TP *kg/d*	CBODu *kg/d*	DO *kg/d*
Ocean Pines WWTP	3.00	6.82	13.65	13.65	34.12	4.55	18.20	22.75	284.32	56.86
Perdue Farm Inc., Showell	1.20	9.10	6.82	6.82	22.75	1.14	1.14	2.27	75.82	27.29

Average Annual Flow *Baseline Loads*	FLOW *mgd*	NH3 *kg/d*	NO23 *kg/d*	TON *kg/d*	TN *kg/d*	PO4 *kg/d*	OP *kg/d*	TP *kg/d*	CBODu *kg/d*	DO *kg/d*
Ocean Pines WWTP	3.00	18.20	36.39	36.39	90.98	4.55	18.20	22.75	284.32	56.86
Perdue Farm Inc., Showell	1.20	14.56	10.92	10.92	36.39	1.14	1.14	2.27	75.82	27.29

Table A18: Environmental Parameters used in the Average Annual Model Scenarios

Segment	Temperature (^oC) Average Flow	Salinity (ppt) AverageFlow	Extinction Coeff. (m^{-1}) Average Flow
1	17.5	30.0	1.7
2	17.5	30.0	1.7
3	17.8	29.7	1.7
4	18.7	29.1	1.9
5	19.6	28.6	2.0
6	20.4	28.0	3.4
7	20.3	27.4	3.4
8	19.6	28.6	2.0
9	19.6	28.6	2.0
10	20.0	28.0	2.2
11	20.1	26.8	4.2
12	20.4	27.2	2.8
13	20.4	27.2	2.8
14	20.8	25.7	2.5
15	21.1	25.1	2.9
16	21.3	25.1	3.2
17	21.5	23.7	3.0
18	22.0	23.3	3.3
19	22.2	22.3	3.3
20	22.6	22.1	2.8
21	23.1	19.5	4.1
22	20.6	5.4	4.8
23	20.0	27.4	2.9
24	20.0	27.4	2.9
25	20.1	26.8	4.2
26	20.1	26.8	4.2
27	20.1	26.8	4.2
28	20.0	2.0	4.2
29	20.6	25.3	2.9
30	20.6	25.3	2.9
31	23.0	21.5	3.9
32	25.8	21.1	6.0
33	18.6	0.1	4.8
34	18.6	0.1	4.8
35	18.6	0.1	4.8
36	18.6	0.1	4.8
37	18.6	0.1	4.8

	Average Flow
Solar Radiation	407.
Photoperiod	0.54

Table A19: Nutrient Flux and SOD Reductions Attributed to Decreased Point Source Loads

Segment	Nitrogen Fluxes mgN/m^2d	Phosphorus Fluxes mgP/m^2d	SOD gO_2/m^2d
13	5%	0%	5%
14	10%	0%	10%
15	20%	0%	20%
16	30%	0%	30%
17	40%	0%	40%
18	50%	0%	50%
19	59%	0%	59%
31	59%	0%	59%
32	59%	0%	59%
33	59%	0%	59%
34	59%	0%	59%
35	59%	0%	59%
36	20%	0%	20%
37	0%	0%	0%

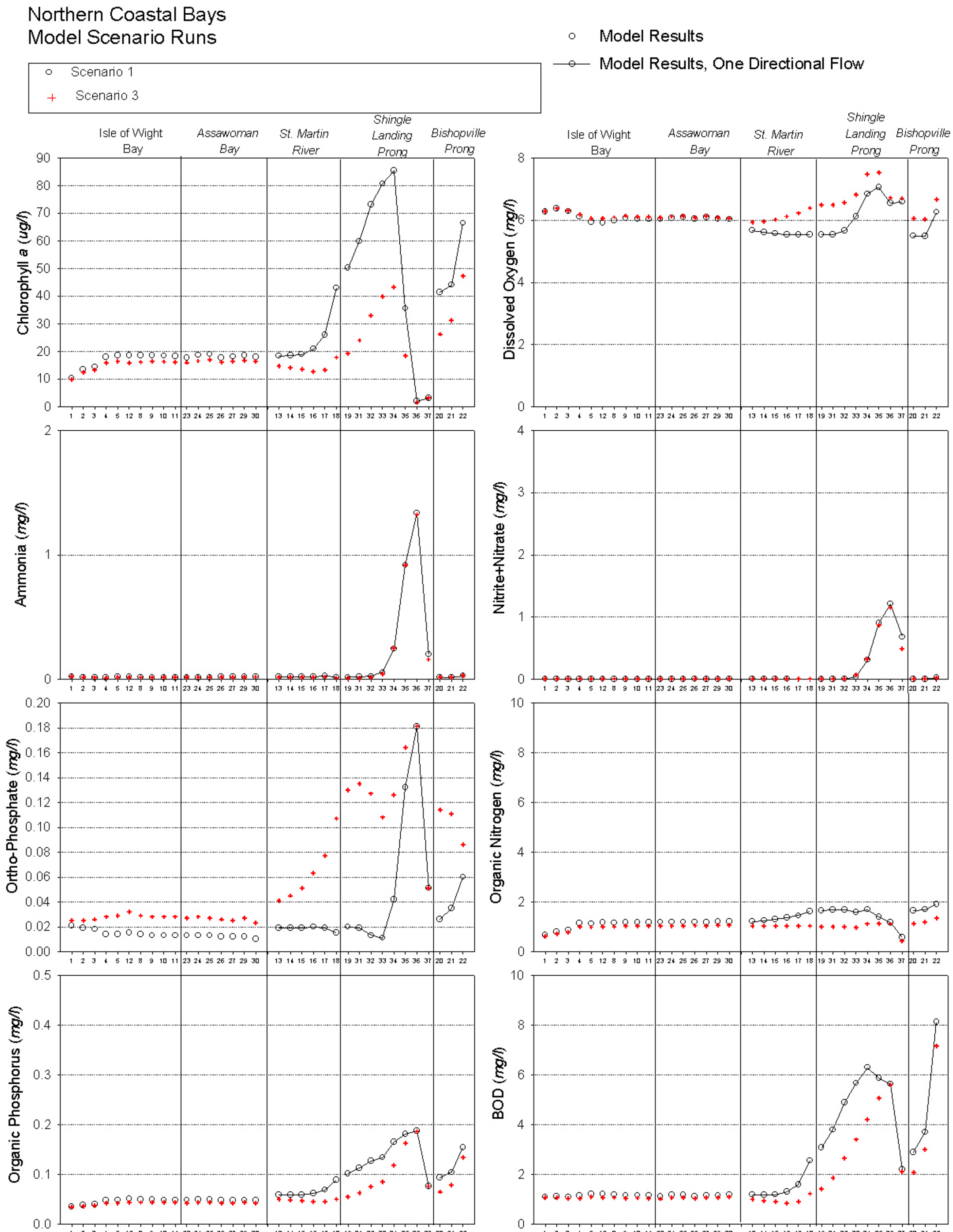

Northern Coastal Bays
Model Scenario Runs
Scenario 1
Scenario 3
Model Results
Model Results, One Directional Flow
Isle of Wight Bay
Assawoman Bay
St. Martin River
Shingle Landing Prong
Bishopville Prong
Chlorophyll a (ug/l)
Dissolved Oxygen (mg/l)
Ammonia (mg/l)
Nitrite+Nitrate (mg/l)
Ortho-Phosphate (mg/l)
Organic Nitrogen (mg/l)
Organic Phosphorus (mg/l)
BOD (mg/l)

Figure A17: Low flow - Baseline Scenario and TMDL Scenario

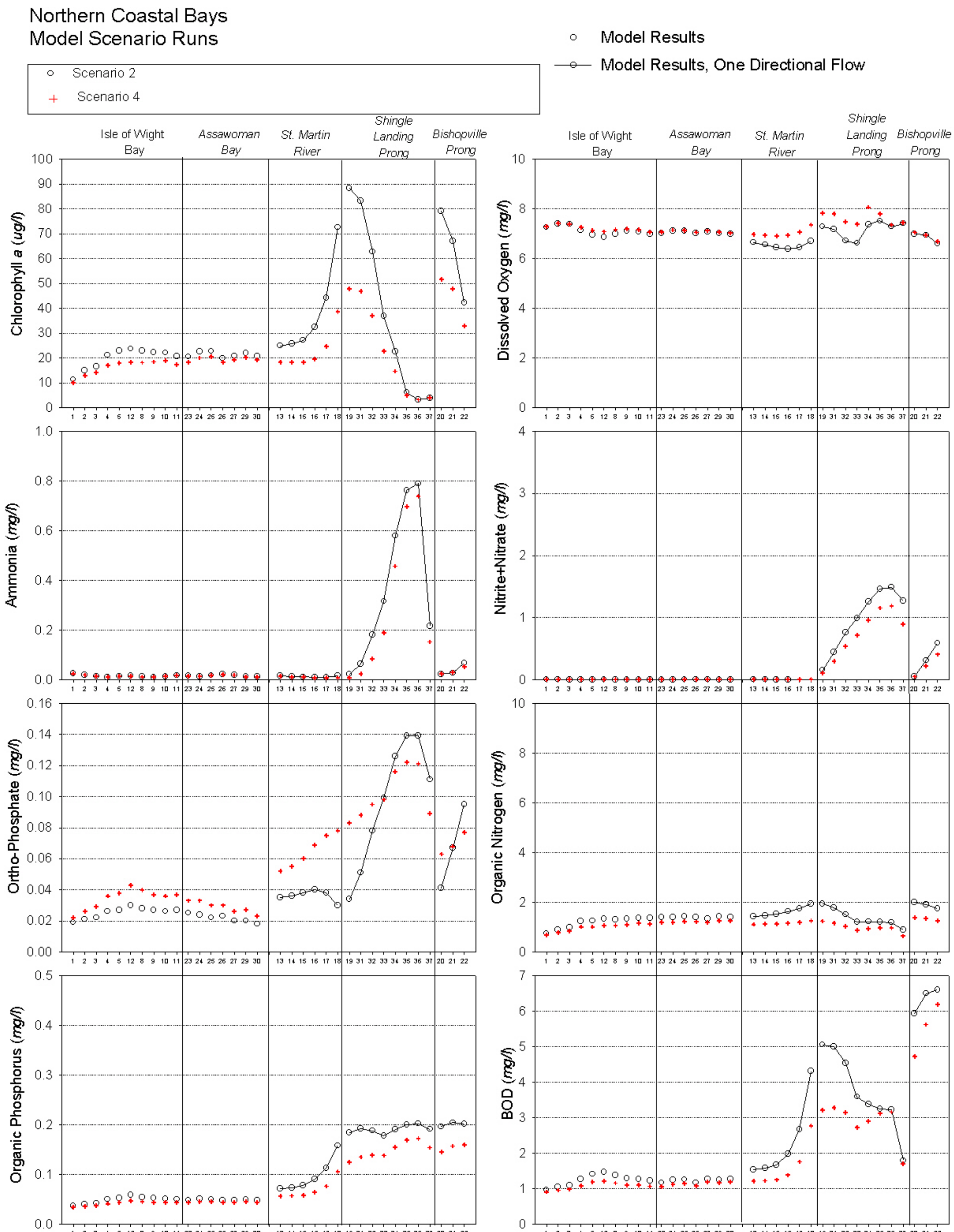


Figure A18: Average Annual - Baseline Scenario and TMDL Scenario

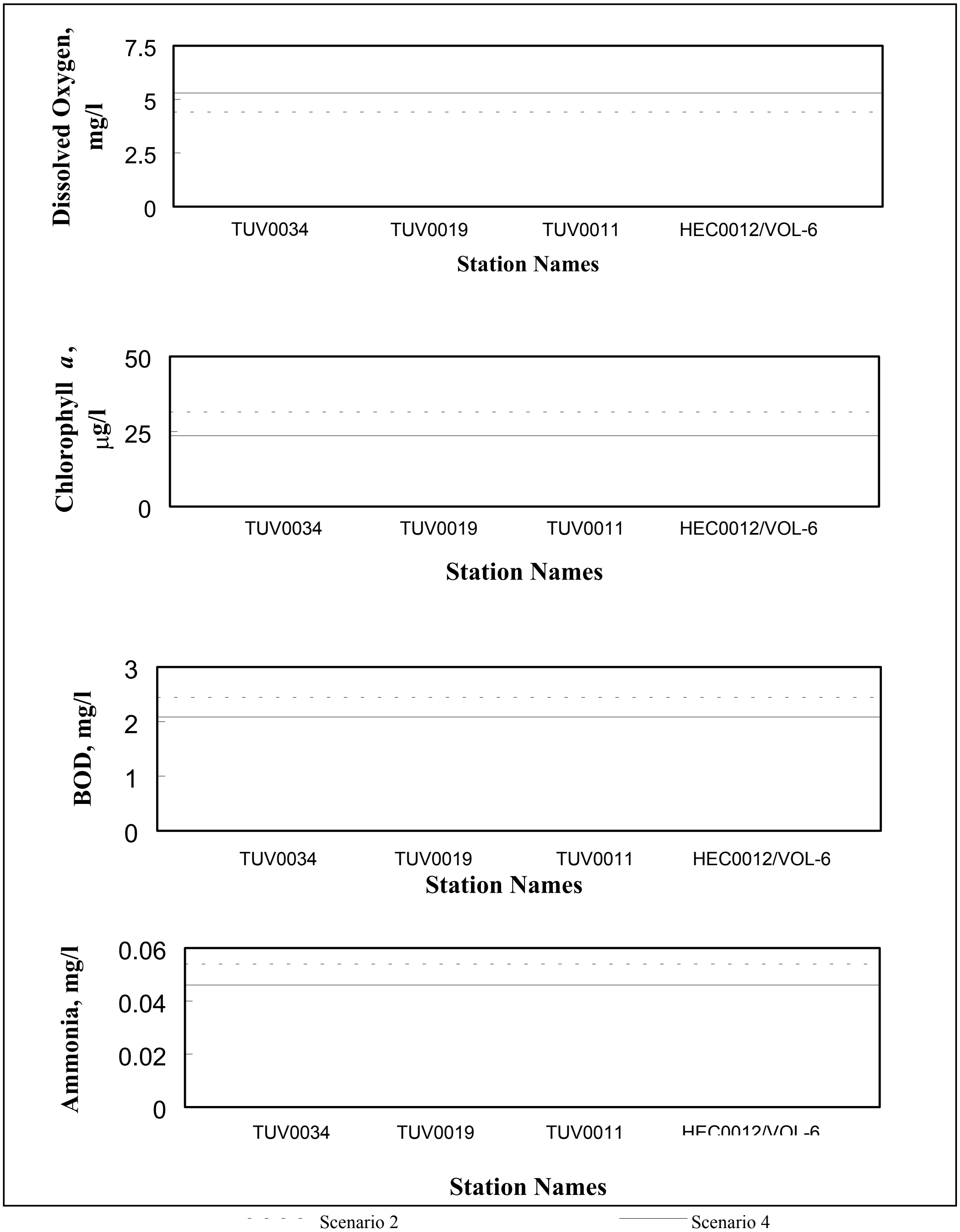

Dissolved Oxygen, mg/l
7.5
5
2.5
0
TUV0034
TUV0019
TUV0011
HEC0012/VOL-6
Station Names
Chlorophyll a, µg/l
50
25
0
Station Names
BOD, mg/l
3
2
1
0
Station Names
Ammonia, mg/l
0.06
0.04
0.02
0
Station Names
Scenario 2
Scenario 4

Figure A19: Average Annual Baseline Scenario and TMDL Scenario for Dissolved oxygen, Chlorophyll *a*, Biochemical Oxygen Demand, and Ammonia in Herring & Turville Creeks

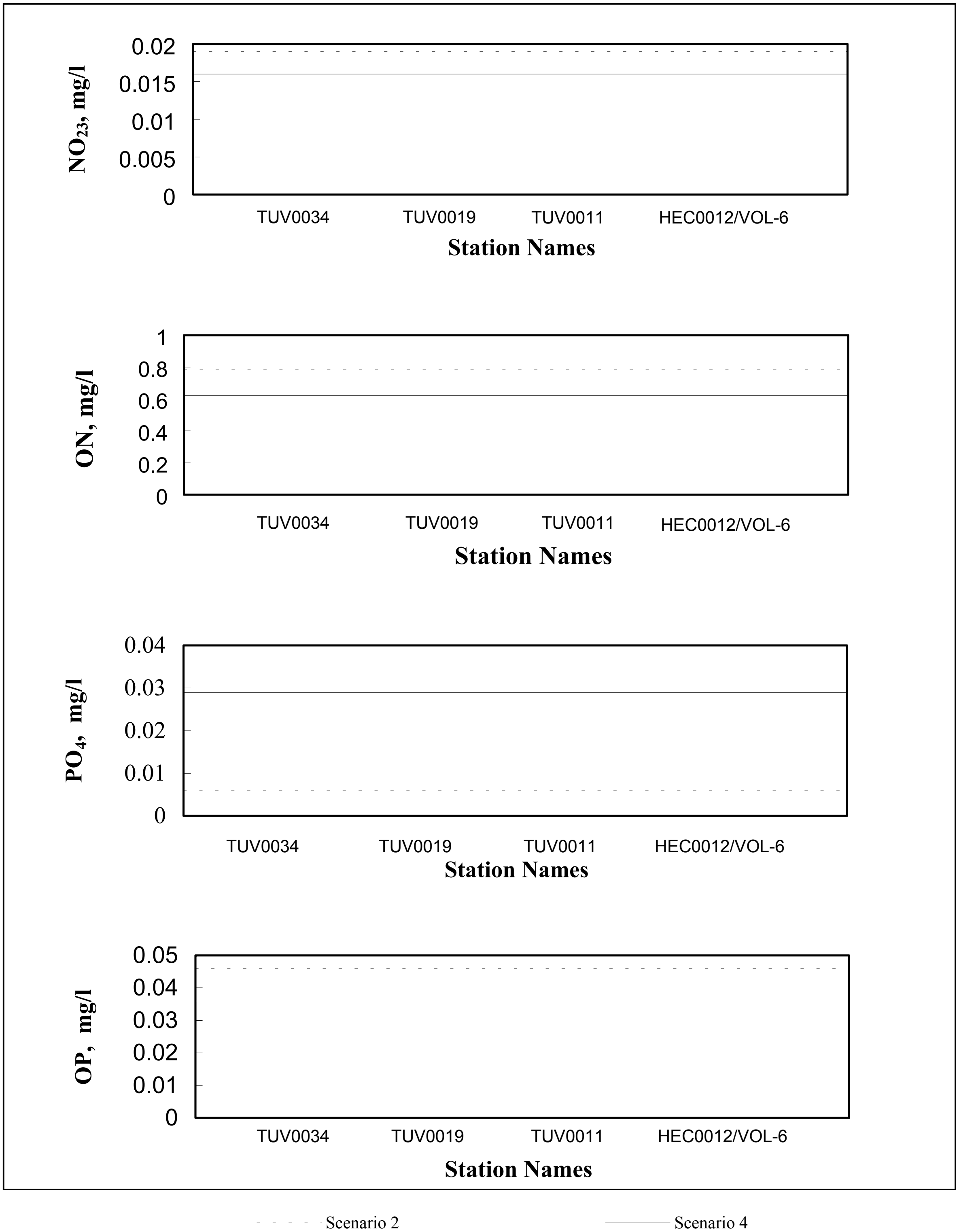


Figure A20: Average Annual Critical Scenario and TMDL Scenario for

Nitrate & Nitrite (NO23), Organic Nitrogen (ON), Inorganic Phosphorus (PO4), and Organic Phosphorus (OP) in Herring & Turville Creeks

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